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Solution Mining of Uranium Administrator's Guide

Western Interstate Energy Board, Denver, CO

Prepared for

Environmental Protection Agency, Denver, C Region VIII

May 79

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SOLUTION MINING OF URANIUM

ADMINISTRATOR'S GUIDE

Western Interstate Energy Board

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ADMINISTRATOR'S GUIDE

FOR

SOLUTION MINING OF URANIUM

Prepared for

WESTERN INTERSTATE ENERGY BOARD/WINB
(formerly the Western Interstate Nuclear Board)
2500 Stapleton Plaza
3333 Quebec Street
Denver, Colorado 80207

Under Contract to the

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Contract No. 68-01-4490

by
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Denver, Colorado

May 1979

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Foreword

The purpose of the Administrator's Guide for Solution Mining of Uranium is to expand the brief coverage of the subject presented in Uranium Mining and Milling--The Need, The Processes, The Impacts, The Choices -- Administrator's Guide (EPA-908/1-78-004). The Guide for Solution Mining of Uranium presents some data not available when the previous guide was prepared. It also greatly expands the discussion of environmental considerations, particularly selection of chemicals injected underground to dissolve the uranium, groundwater quality and restoration methods.

Consistent with the previous Administrator's Guide, the information is intended to be useful to local, state, and federal administrators, legislators, planners, and regulators involved in the review or approval process for uranium projects.

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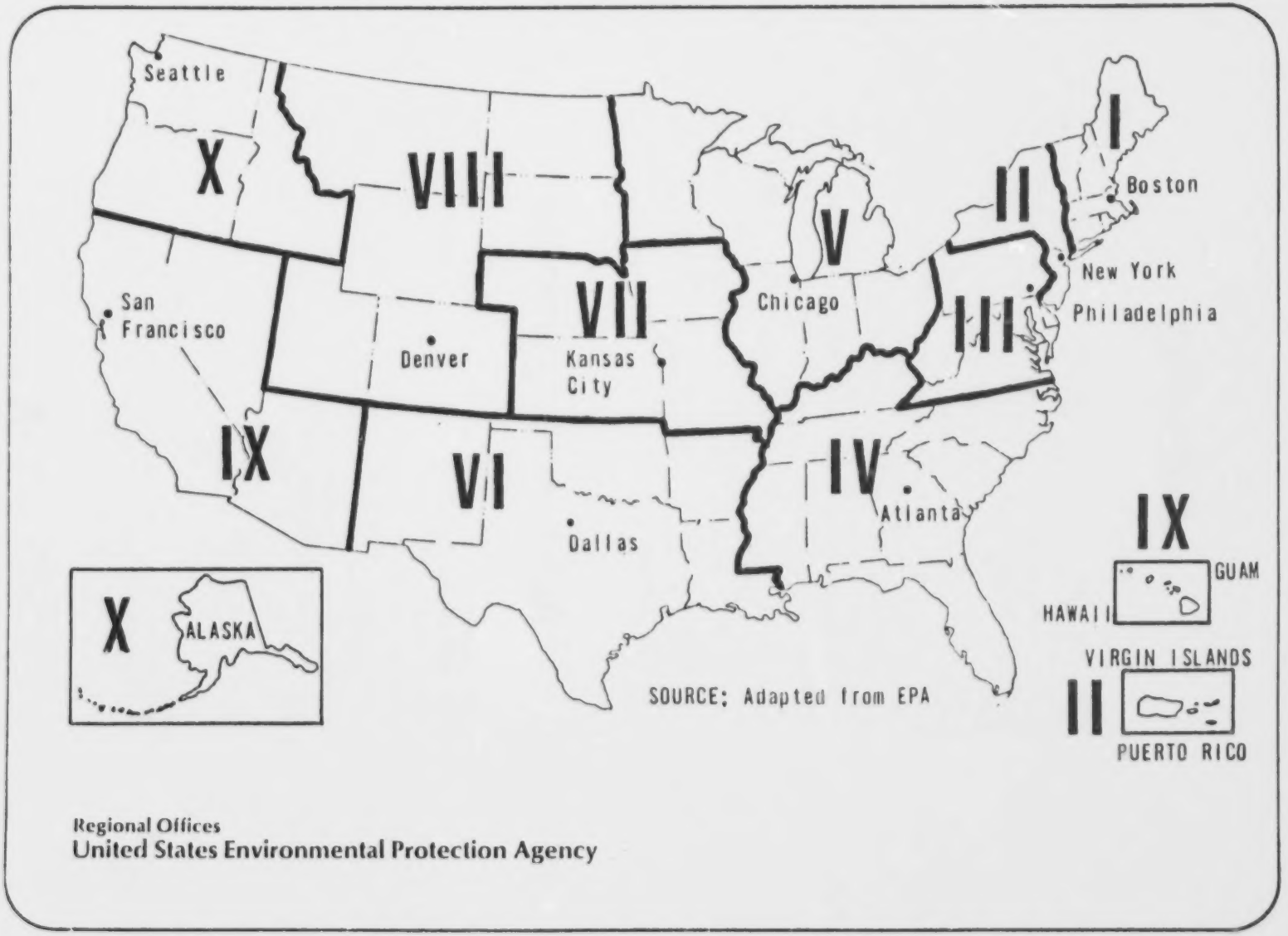

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Chapter 1

Introduction

1.1 Process Definition, Advantages and Disadvantages

The term solution mining as used in the Guide refers to dissolving uranium with leaching solutions from an ore body that is left in place. In situ leaching is another term used to describe solution mining.

The solution mining process discussed in the Guide produces yellow cake (U_3O_8) through the following process steps:

- Drilling into the ore body
- Injecting a leaching solution (lixiviant)
- Circulating the lixiviant through the ore body to dissolve uranium
- Recovering the uranium rich solution
- Extracting uranium (yellow cake) from the solution
- Regenerating the lixiviant for reuse

Solution mining of uranium is a relatively new practice and few commercial operations have been licensed to date. However, in-

terest in the technique is increasing. In January of 1978 the U.S. Bureau of Mines listed 23 sites involving solution mining in Texas, Wyoming, New Mexico, and Colorado. In addition, officials in South Dakota, Utah, Arizona, and Montana have received inquiries about establishing pilot-scale operations.

Examples of recently licensed solution mining projects are Wyoming Mineral Corporation's Irigaray Project which anticipates production of 500,000 lbs of U_3O_8 per year, and Exxon's Highland Project with an expected annual production of 750,000 lbs. The latter production rate is about equivalent to the output of a 1000 ton per day conventional mill processing 0.1% ore. Although these projects represent only a small fraction of the current annual U.S. production of about 20,000 tons of U_3O_8, they are significant as they may well set the precedent for other deposits that probably could not be mined using conventional methods.

Increasing interest in this technique is understandable because solution mining offers several advantages compared to conventional mine-mill complexes. The advantages include:

- Lower capital costs, improved cash flow, and generally, greater return on investment capital.
- Shorter lead time to production.
- Deeper, lower grade ore can be mined and thus the recoverable reserves of uranium increase.
- Reduced environmental impact including:

-Minimal surface disturbance

-No mine spoil

-No mill tailings

-Less air pollution

-Lower release of radionuclides (particularly radon 222 gas)

-Minimal radiation exposure to personnel

-Lower consumption of groundwater

-The mine site may be returned to unrestricted use after radioactive and toxic solid wastes have been removed or isolated from the environment.

These apparent economic and environmental advantages of solution mining would appear to make it a very attractive uranium recovery method. However, there are significant limitations and disadvantages to the process:

- Relatively few deposits are amenable to this mining method because the geology and hydrology of candidate ore bodies must satisfy rather restrictive requirements.
- Uranium recovery by solution mining may be significantly less efficient than if the ore body could be mined and processed by conventional means.
- Potential for groundwater contamination is greater for in situ leaching than conventional mining because the chemical solutions injected to recover the uranium may escape the well field.
- Because of inherent limitations in ability to characterize local subsurface geologic and hydrologic conditions, there are uncertainties in predicting the efficiency of the mineral extraction process.

1.2 Organization

To achieve the purpose of this Guide, the following subjects will be addressed in the chapters that follow:

Chapter 2 - "DEVELOPING A SOLUTION MINING OPERATION." Describes the sequence of events required to develop a candidate ore body for production.

Discusses alternates and key factors to be considered in selecting an environmentally compatible lixiviant.

Chapter 3 - "ENVIRONMENTAL IMPACTS FROM MINING." Describes the impacts during mining on air quality, land use, surface water, and groundwater quality. Comparisons are made with conventional mining practices as appropriate.

Chapter 4 - "RESTORATION OF GROUNDWATER QUALITY." Summarizes the effect of leaching solutions on groundwater in the mining zone and provides an overview of the results from recent pilot-scale restoration efforts.

Chapter 5 - "REGULATIONS AND PERMITS." Lists applicable federal and state laws, discusses agreement and non-agreement states and EPA and NRC responsibilities for a solution mining project.

A Glossary of specialized technical terms is provided at the end of the Guide to assist the reader.

1.3 Comments and Updating

Since solution mining will continue to be applied to a wide variety of geological settings in the future, new problems and innovative solutions to problems will be of considerable interest

to users of the Guide. Readers and users are invited to submit information and comments to:

U.S. Environmental Protection Agency
Region VIII
1860 Lincoln Street
Denver, Colorado 80203

Attention: Mr. Paul B. Smith

Chapter 2

Developing A Solution Mining Operation

2.1 Criteria

Ore bodies must meet the following criteria for solution mining (Hancock, 1977):

- The ore body should be a relatively horizontal bed underlain by impermeable strata.
- The ore body should be below the water table.
- The permeability, porosity, and hydrology of the deposit must be favorable.

Most sandstone formations, like the uraniferous sandstones in Texas and Wyoming, exhibit sufficient permeability for in situ leaching. In Wyoming, sandstone with an average permeability of 1088 millidarcys has been measured and the lower permeability limit is generally considered to be 200 to 500 millidarcys (Chamberlain 1979). For comparison, the permeability of underlying shale is typically 0.1 millidarcys (NRC, NUREG-0489,

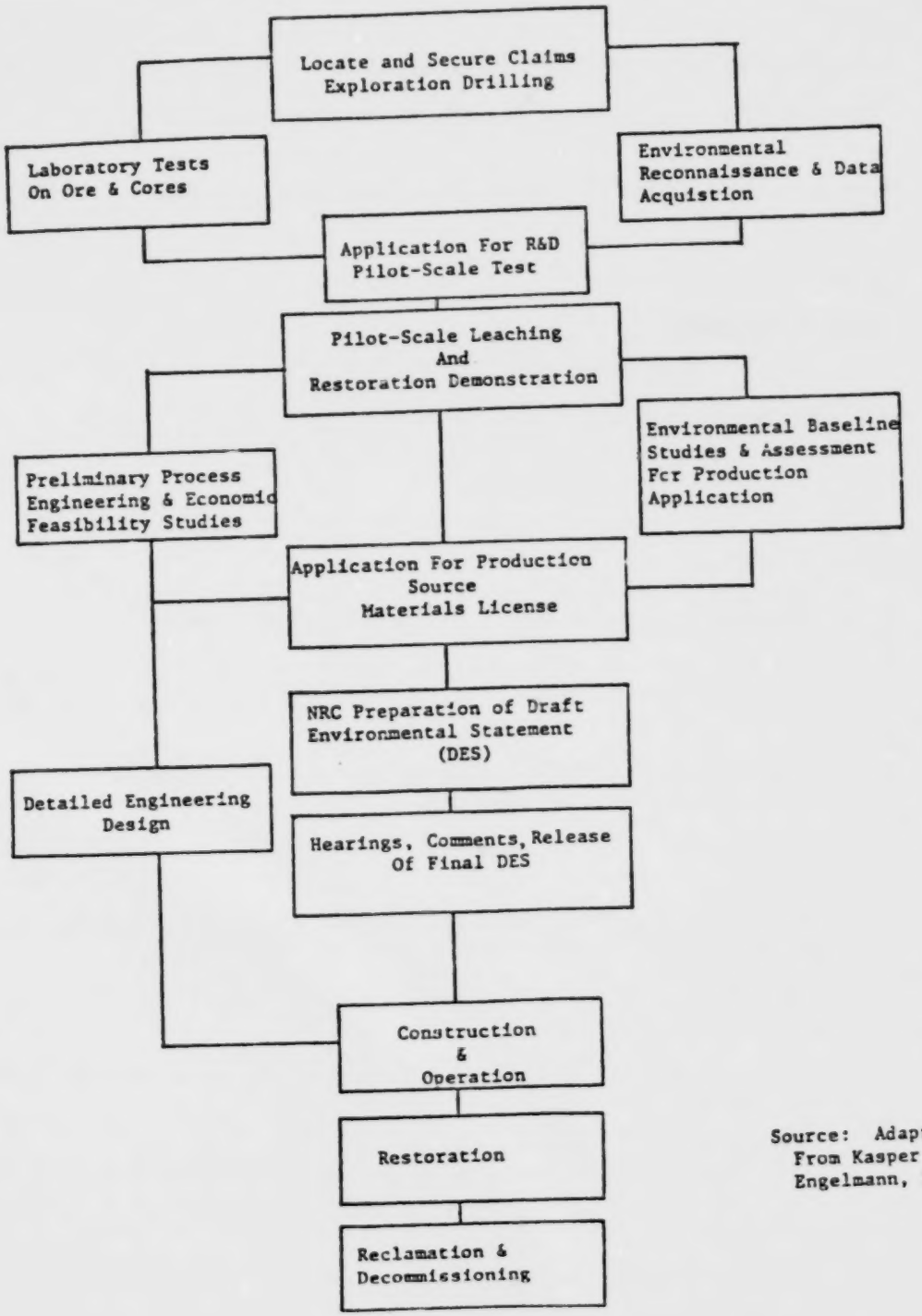
1978). For the definitions of permeability, porosity and Darcy, please refer to the Glossary.

2.2
Development Schedule

Development of a solution mining property is similar to development of a conventional mine. Exploration drilling is followed by development drilling to determine the grade, size, depth, and shape of the deposit. The cores are logged and analyzed to identify the physical and chemical properties of the ore, including the permeability and porosity of the rock. Hydrological studies are conducted and pumping tests are performed to determine the natural direction and rate of water flow through the formation. Samples of the core are also subjected to bench scale experiments to determine the amenability of the ore to leaching.

If preliminary feasibility studies are encouraging, field tests are performed to confirm the ore's amenability, to develop additional hydrological data and to demonstrate that the groundwater can be restored to the conditions which existed prior to injecting lixiviants into the aquifer. This latter objective of the field studies is most critical since without demonstration of groundwater restoration, the permits and licenses required for full scale production will be denied.

The relationship between technical and environmental studies and license applications is illustrated in Figure 2-1. Of course the licensing and permitting procedures significantly impact the



Source: Adapted From Kasper & Engelmann, 1978

Figure 2-1
Relationship of Technical and Environmental Studies and License Applications (Non-Agreement States, See Chapter 5)

schedule of activities. An example of how the regulatory process affects the development schedule is displayed in Figure 2-2.

Key permit approvals and regulations are discussed in Chapter 5.

2.3 The Process

The major components of the solution mining process can be summarized as follows:

- Leaching the uranium with lixiviants delivered to the ore zone through a network of injection wells.
- Recovering the uranium-bearing liquor by pumping solution from the ore-bearing formation at strategically placed production wells.
- Treating the pregnant liquor to remove certain deleterious impurities such as calcium.
- Extracting the dissolved uranium by adsorption onto a resin.
- Regenerating the uranium barren lixiviant with the appropriate chemicals for continued use underground.
- Desorbing (eluting) the uranium from the resin with an appropriate solution.
- If necessary, further concentrating the desorbed uranium by solvent extraction.
- Precipitating the uranium and preparing the yellow cake for market. (This may include product dewatering, drying, and packaging or shipping the yellow cake as a thickened slurry.)
- Restoration of the groundwater to acceptable conditions.
- Disposal of wastes and site decommissioning.

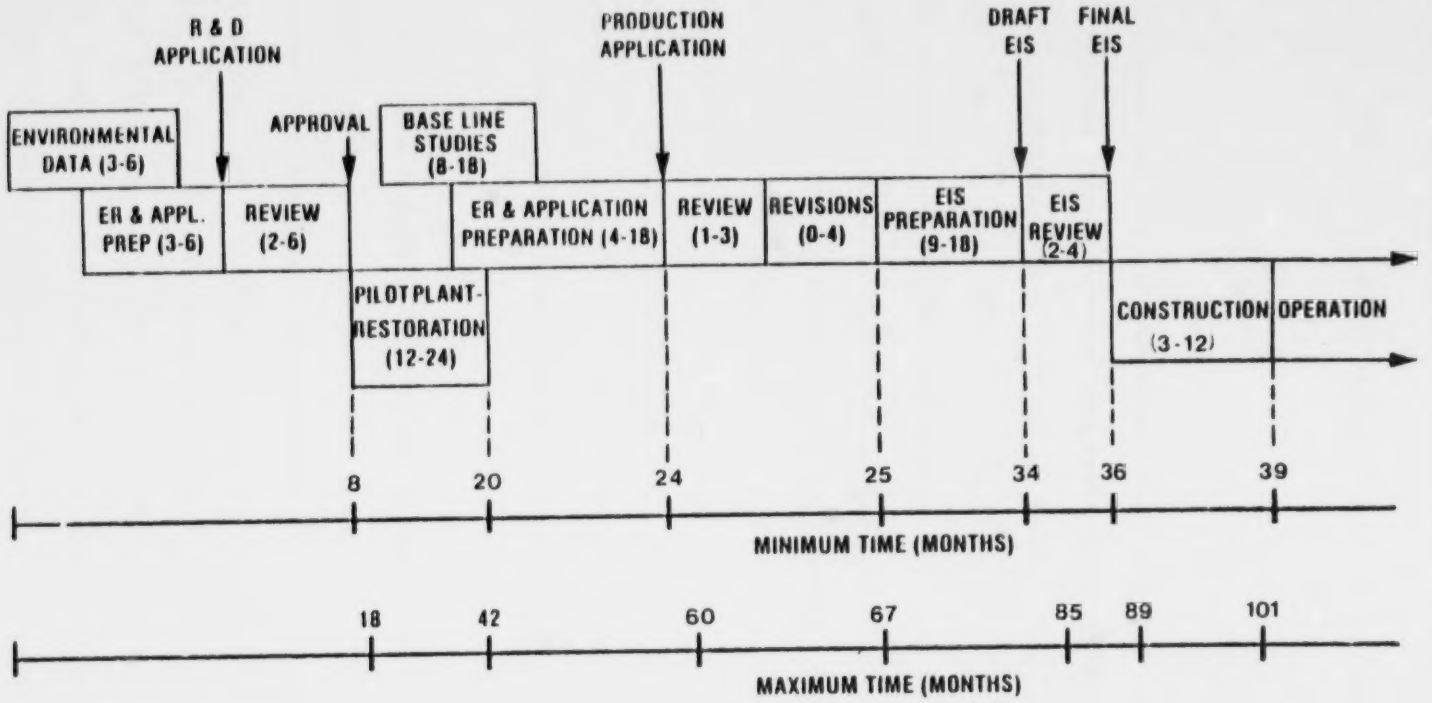


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Figure 2-2
Time Schedules for Permitting Process. (Numbers in Brackets Refer to Months Required for Completion of Task.)

Figure 2-3 is a schematic of the uranium recovery process using conventional lixiviants.

Well Field Operations

Well development is perhaps the most important aspect of solution mining. Wells for injecting the leaching solution are typically 4 inches in diameter and cased with PVC pipe cemented to the surface. Recovery wells are similar in construction but are usually larger in diameter. The continuous casing is interrupted where the well intersects the mineralized zone to allow introduction of a lixiviant. An example of well construction and a vertical cross section of a typical well field is shown on Figure 2-4 (Wyoming Mineral Corp., 1976). Several different types of well patterns have been investigated, but the five-spot pattern is probably the most common. A typical five-spot pattern used at U.S. Steel's property at Clay West, Texas, is shown on Figure 2-5 (White, 1975).

Injection of a lixiviant forms a hydraulic gradient within the uraniferous aquifer. This gradient, together with the withdrawal rate at the production well, determines the direction and velocity of solution flow. Solution flow is toward the recovery well, since the hydraulic head at that point is less than that developed at the point of injection. Thus, the pumping rates and pressures can be used to confine the lixiviant to the desired area. Normally, more solution is withdrawn than injected to prevent solution migration and contamination of the groundwater.

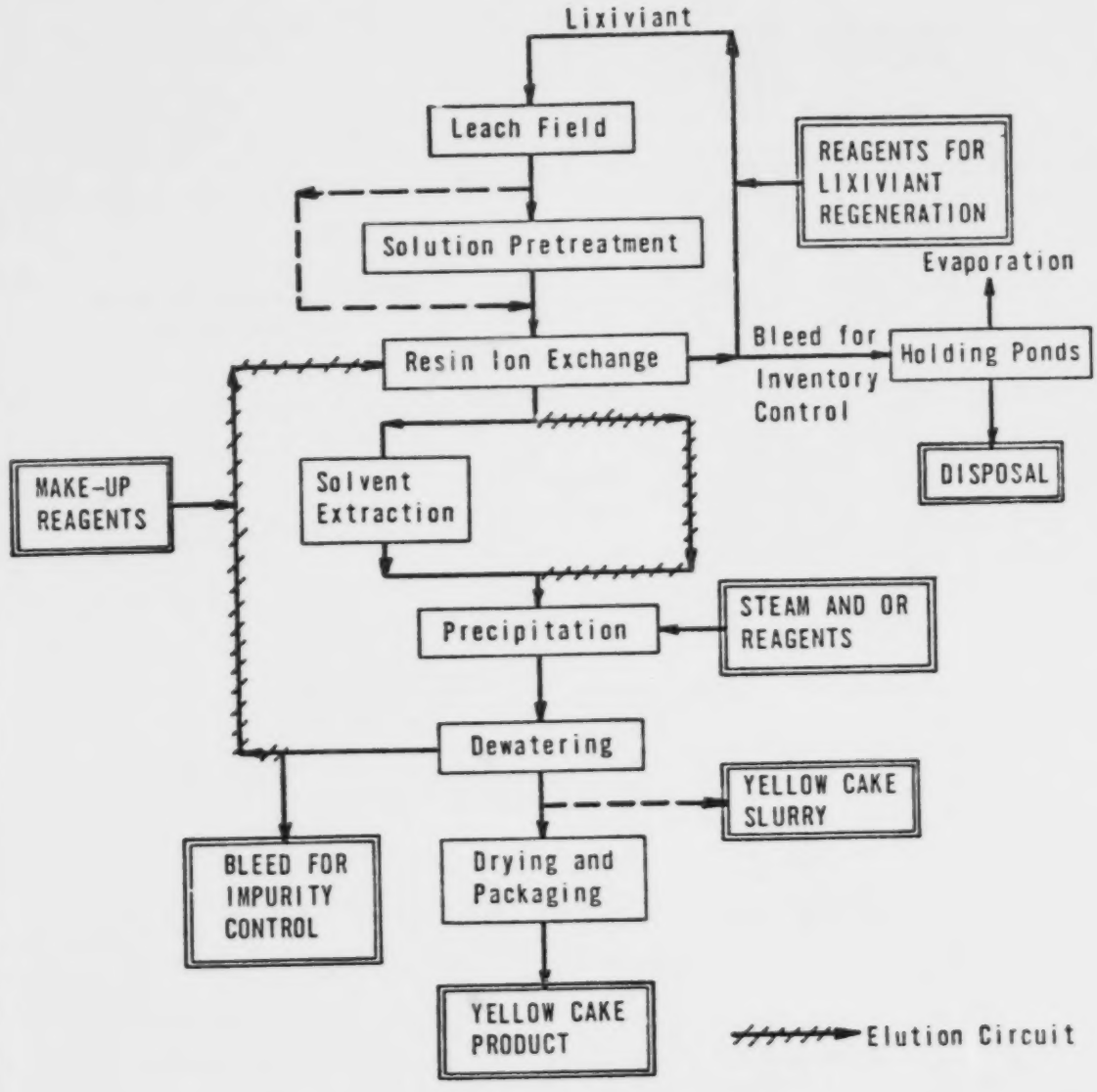
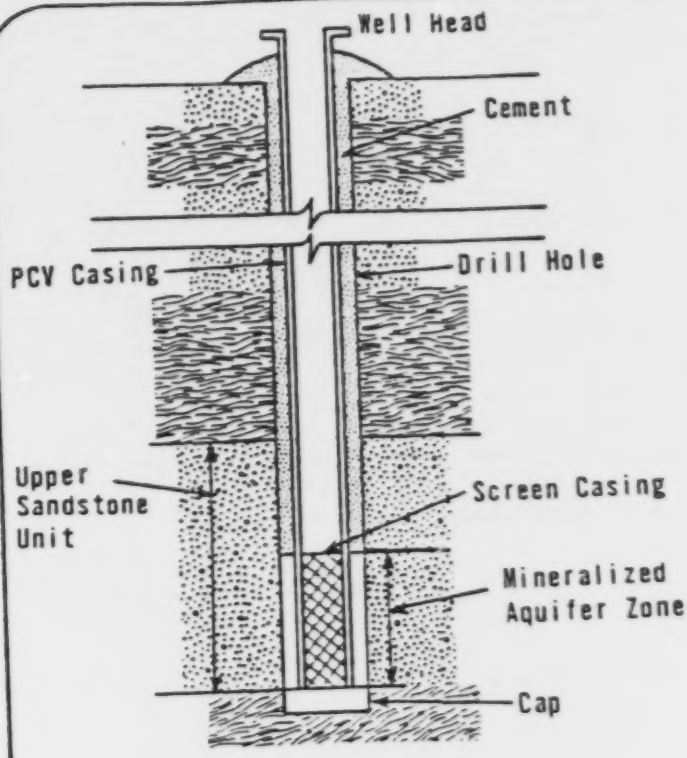


Figure 2-3
Uranium Recovery Process Schematic, Conventional Lixiviants



SOURCE: Wyoming Mineral Corporation

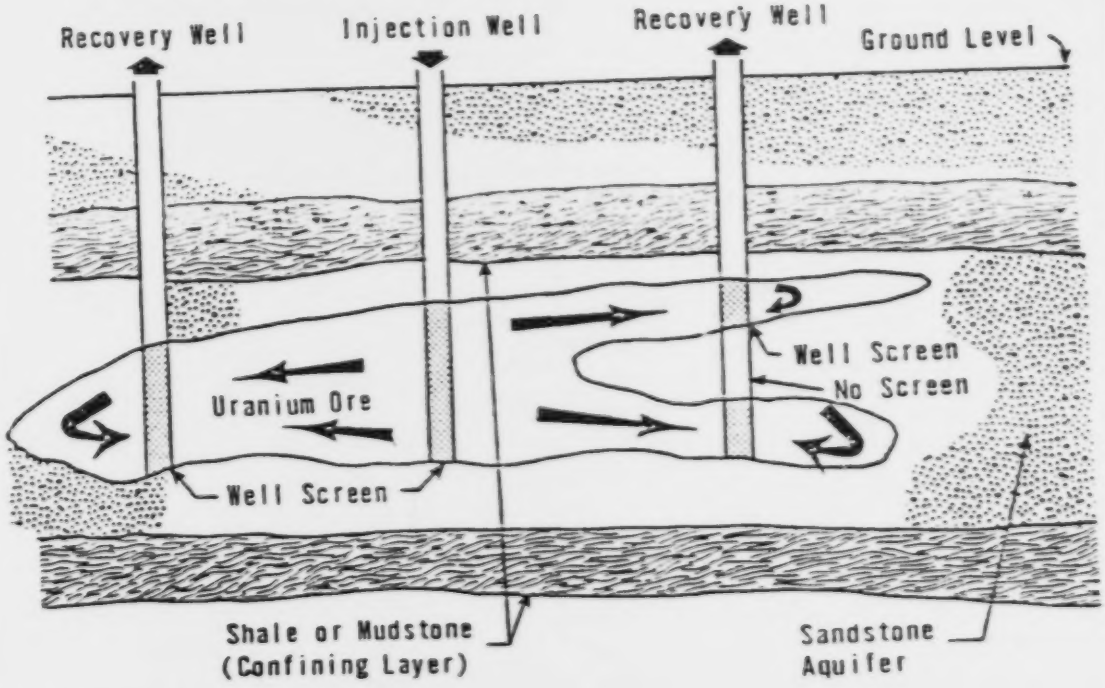


Figure 2-4
Well and Well-Field Design for Solution Mining

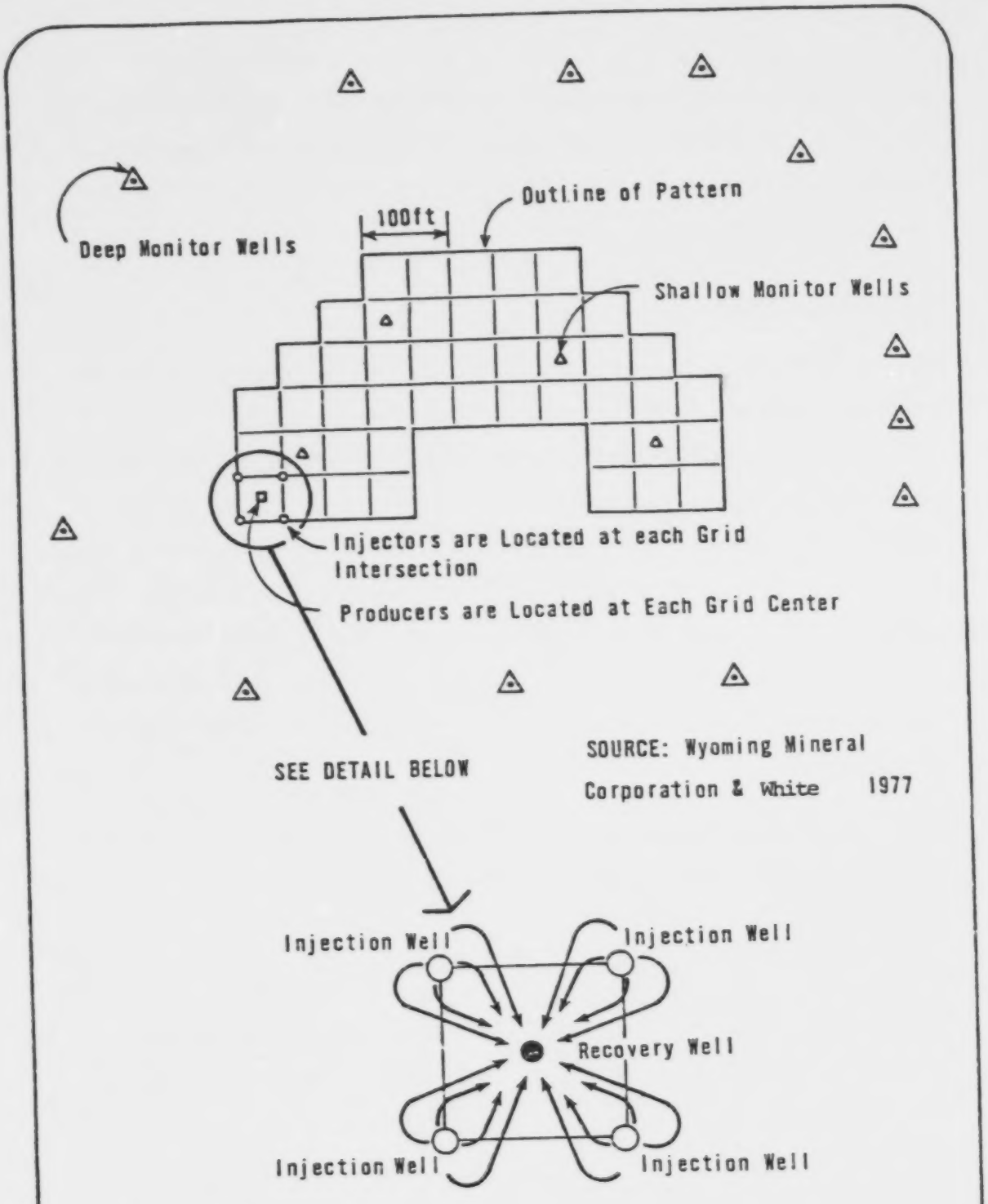


Figure 2-5
Typical Well-Field Pattern

Monitor wells are placed in the aquifer as well as outside the ore zone to detect escaping solution. If solution migration is noted, the hydraulic gradient can be adjusted by pumping to force the solution back into the well field.

Recovery Process

In general, the recovery process is similar regardless of the type of lixiviant used. One exception is the process envisioned by Wyoming Minerals for recovering uranium from calcium or magnesium carbonate lixiviants. As illustrated in Figure 2-6, an impure uranium product might be precipitated directly from the leach solution and shipped to an existing facility for purification. This process would eliminate the need for concentrating the dissolved uranium by ion exchange and may prove economically and environmentally attractive under certain circumstances.

The recovery processes generate waste products at various points in the circuit. These waste streams include:

- Fluid removed (bleed) from the ion exchange uranium barren lixiviant (barrens) equal to the amount of ex-cess solution recovered from the well field. (More solution is recovered from the field than is injected to insure the lixiviant does not migrate beyond the ore zone.)
- Solid waste product from the calcium removal step.
- Bleed from the ion exchange elution circuit to control the build-up of impurities.

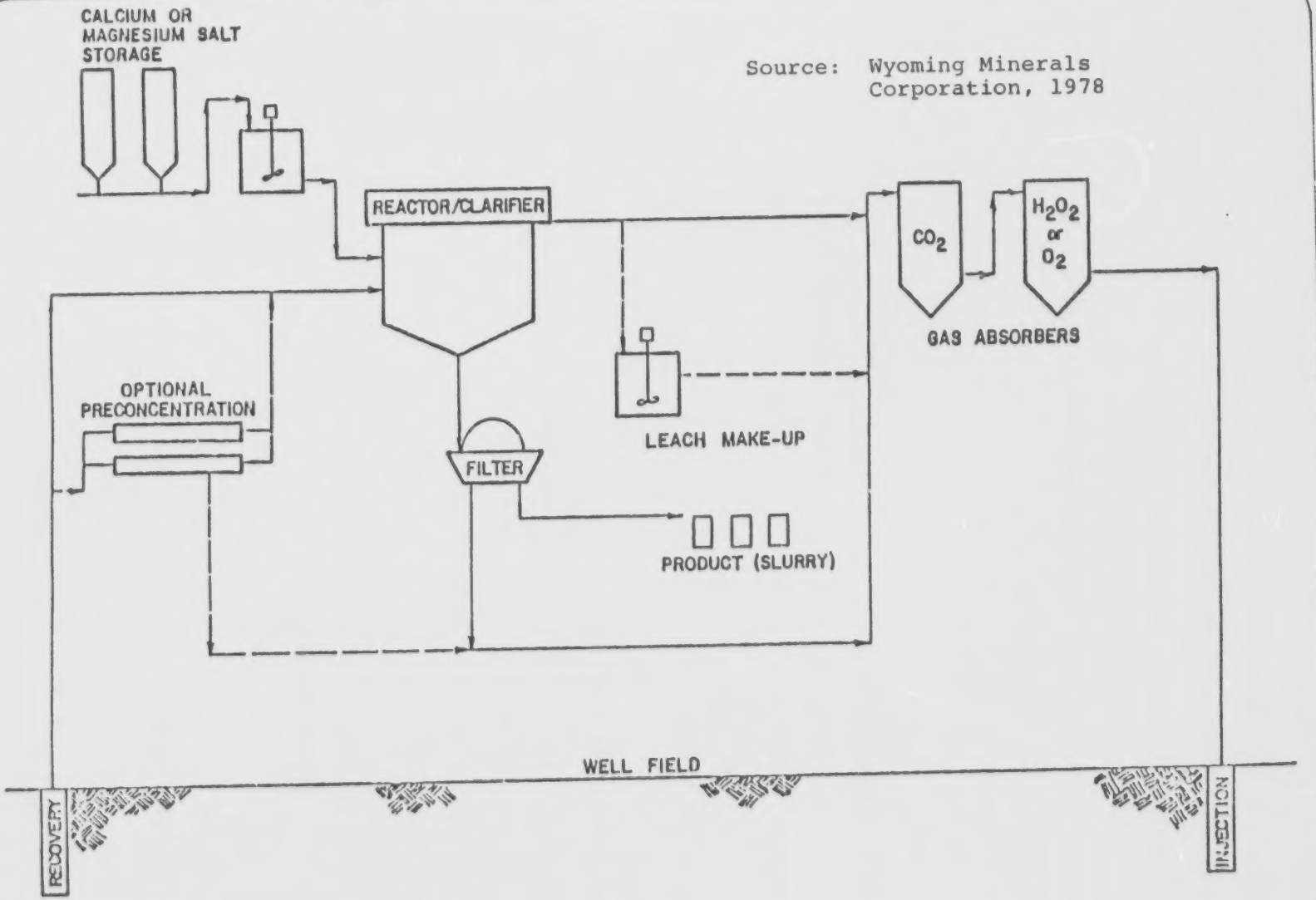


Figure 2-6
Uranium Recovery Process Schematic, Calcium or Magnesium Bicarbonate Lixiviant

- Solution used to clean the wells.
- Solutions generated during the restoration process.

These wastes and other environmental impacts are discussed in Chapters 3 and 4.

2.4 Lixiviant Selection

The choice of reagents used to dissolve the uranium is becoming increasingly important to the in situ leaching process since the type of lixiviant used during the actual leaching cycle will have a substantial effect on the restoration process. There are necessarily two chemical ingredients in the lixiviant to solubilize and oxidize the uranium in the ore. The oxidant is added to the lixiviants to oxidize uranium to a readily soluble form. Hydrogen peroxide (H_2O_2), air, and oxygen have been used for this purpose. Either alkaline or acid lixiviants produce soluble compounds of uranium.

Since the chemistry of each ore deposit is expected to be different, the results obtained at one site cannot be directly applied to other sites. For this reason, core samples must be obtained at each site and subjected to bench-scale experiments to determine the following:

- Uranium extraction vs. lixiviant type and lixiviant strength.
- Effect of lixiviant type on permeability.
- Mobilization of impurities vs. lixiviant type.
- Effect of lixiviant type and concentration on the ion exchange properties of the gangue constituents. (These studies provide information pertinent to restoration.)

These preliminary laboratory studies provide the information necessary to select the type of lixiviant best suited to treat the particular deposit. The preliminary studies are followed by more detailed laboratory investigations to optimize lixiviant strength and develop the criteria required for design of the demonstration pilot plant.

Lixiviant Type

There are basically two types of lixiviants, alkaline and acid. Both types of lixiviants offer advantages and disadvantages and lixiviant selection is based on site specific conditions. Unlike conventional milling, the choice of reagent is influenced primarily by underground performance, including factors such as selectivity, maintenance of permeability, suitability to recirculation, and groundwater contamination. For example, bicarbonate-carbonate (alkaline) lixiviants are usually not effective in leaching uranium from conglomerate ores, since the HCO_3-CO_3 cannot dissolve the other minerals encasing the uranium. Sulfuric acid must generally be used in such cases. Bicarbonate-carbonate

lixiviants are effective for in situ leaching of sandstone type ores because the uranium is usually exposed as a precipitate on the surface of the sand grains. Although bicarbonate-carbonate lixiviants mobilize greater quantities of isotopes and usually do not achieve the high recovery levels attainable with acids, carbonate lixiviants are extremely selective. Sulfuric acid (also other acids) often reacts with clays, calcite, silica, etc. to form compounds which may reduce the permeability of the formation. Acids also dissolve other metallic impurities which may complicate the recovery and the restoration processes.

Acid Lixiviants

Many acids are capable of dissolving uranium, but sulfuric acid (H_2SO_4) is used almost exclusively due to cost and availability. Sulfuric acid solubilizes the uranium by forming uranyl sulfate and complex uranyl sulfate ions in solution.

The Bureau of Mines reports (Tweeton et al, 1979) that in situ acid leaching at Rocky Mountain Energy's Nine Mile Lake site located near Casper, Wyoming dissolved fewer impurities than were anticipated. The results of the Bureau's studies demonstrated that the acid lixiviant contained lower concentrations of selenium and molybdenum than the standards established for drinking water and the concentrations of arsenic were not significantly greater than in typical alkaline solutions. These relatively low impurity levels were maintained by removing 7% of the total production flow. These preliminary findings also indicated that

restoration of the acid leached aquifer will be less complicated than a comparable alkaline leached formation.

Alkaline Lixiviants

In spite of these encouraging preliminary results with acid lixiviants at the Nine Mile Lake property, other Wyoming deposits owned by Rocky Mountain Energy, and one deposit in Texas, alkaline lixiviants have been selected for leaching at most of the other deposits.

The most common alkaline lixiviants are bicarbonate-carbonate (HCO_3-CO_3) solutions of ammonia (NH_3) or sodium (Na), although Wyoming Minerals Corp. considered the use of calcium (Ca) or magnesium (Mg) bicarbonate at the Keota site in Weld County, Colorado. Other investigators (De Vries 1978) have reported successful results with potassium bicarbonate ($KHCO_3$). The alkaline lixiviants dissolve uranium by forming stable soluble uranyl tricarbonate complexes.

As previously indicated, of the several different types of alkaline lixiviants employed, only sodium and ammonium bicarbonate-carbonate solutions have been utilized on a commercial scale. This is understandable since operators were familiar with the use of sodium carbonate solutions in conventional mills and technical information had been developed previously on leaching uranium with ammonium carbonates.

Solutions of ammonium bicarbonate-carbonate are the most popular of the two commercially used alkaline lixiviants. This is also understandable since most uraniferous formations contain clays that swell upon contact with sodium. The sodium ion exchanges with other cations on the clays and the subsequent swelling can reduce the permeability of the formation significantly. This ion exchange phenomena also occurs with ammoniacal lixiviants, but the radius of the ammonia ion is similar to the radius of the hydrated clay ions and thus, the swelling is not severe. Notable exceptions to the use of ammoniacal leaching solutions include Exxon's in situ operation in Wyoming and Mobil Oil's project in Texas. Both operations intend to use sodium bicarbonate/sodium carbonate lixiviants.

Alternate Lixiviants

Ammonium lixiviants pose some unique problems. First, ammonia can convert to nitrates when oxygen or oxygen supported bacteria are present in the solution. In turn, nitrates may be detrimental to humans and livestock. (Whether or not a production aquifer possesses the chemical environment necessary for nitrate formation is a controversial subject, however.) Second, the ammonia adsorbed by the clays is released very gradually and as a result, tremendous volumes of solution are required to flush the aquifer and return the chemistry of the groundwater to an acceptable condition. This restoration is both time consuming and costly.

For these reasons, interest in alternate lixiviants such as calcium, magnesium, and potassium bicarbonate is growing. Leaching with oxygenated water or water saturated with carbon dioxide (CO_2) is also being considered, but the chemistry of the existing groundwater must be favorable for these systems to be effective. Although it is generally recognized that these lixiviants will not extract uranium as efficiently as ammonium lixiviants, the restoration process may be greatly simplified and the potential impact on groundwater may be reduced significantly.

According to Wyoming Minerals, the calcium or magnesium bicarbonate would probably be produced on site using water saturated with CO_2 gas to dissolve the calcium or magnesium salts. The chemistry of the resulting lixiviant is compared to other leaching solutions in Table 2-1. Note that the reported values represent the anticipated composition of leach solution after it has reached equilibrium with the aquifer.

Unfortunately, additional specific data pertaining to alternate lixiviants has not been published but it appears that the use of lixiviants other than bicarbonates/carbonates of ammonium or sodium and sulfuric acid will receive increasing acceptance in the near future.

Component	Ammonium Bicarbonate Lixiviant	Sodium Bicarbonate Lixiviant	CaIcium-Magnesium Bicarbonate Lixiviant	Sulfuric Acid Lixiviant
NH_4 (ppm)	0 - 3,500	(Baseline)	(Baseline)	(Baseline)
Ca (ppm)	10 - 500	10 - 500	50 - 700	50 - 2,000
Mg (ppm)	20 - 200	20 - 200	20 - 1,500	20 - 1,000
Na (ppm)	100 - 2,000	200 - 3,500	100 - 2,000	100 - 1,000
K (ppm)	10 - 100	10 - 100	10 - 100	10 - 100
(CO_2) (ppm)	---	---	500 - 2,000	0 - 400
HCO_3 (ppm)	850 - 10,000	850 - 10,000	850 - 10,000	---
Cl (ppm)	20 - 3,500	20 - 3,500	50 - 500	50 - 500
SO_4 (ppm)	50 - 1,000	50 - 1,000	50 - 1,000	50 - 5,000
(O_2) (ppm)	0 - 2,000	0 - 2,000	0 - 2,000	0 - 2,000
U_3O_8 (ppm)	1 - 15	1 - 15	1 - 15	1 - 15
Ra-226 pCi/l	10 - 500	10 - 500	10 - 500	10 - 500
pH	6.5 - 9.0	6.5 - 10.5	6.0 - 8.5	1.0 - 2.0

Source: Adapted from Wyoming Minerals Corporation, 1978

Table 2-1
Composition of Injected Leach Solutions

Chapter 3

Environmental Impacts from Mining

Solution mining of uranium offers an attractive alternative to other uranium mining methods because of reduced environmental impacts. Significant advantages of solution mining stem from minimal disturbance of the land surface and underlying ore deposit during the mining process. The land may be returned to its former and unrestricted use once groundwater quality is restored, the surface is reclaimed, and the facility is decommissioned.

The main environmental concern with solution mining is degradation of groundwater quality by escape of lixiviant or other contaminants from the ore zone into adjacent groundwater. Residual lixiviant or contaminants produced by reactions with the lixiviant must be removed sufficiently to insure that groundwater quality will be restored. Once lixiviant control and restoration procedures are successfully demonstrated in a variety of geological settings, concerns about the adverse effects on groundwater quality may be lessened.

Improper abandonment of solution mining wells is another important environmental concern. From the early days in this country, wells have been abandoned by merely covering the hole with a board or sheet of metal, often without even welding or sealing in place, in a feeble attempt to protect the public or livestock from the hazards presented by an unexpected hole in the ground. Such practices occurred because the environmental implications of unplugged holes were not appreciated or because people just didn't care about the hazards to the environment or to ground water quality. Unplugged or inadequately abandoned wells can provide a connection between and commingling of poor and good quality groundwater aquifers or provide a conduit for hazardous residual mining fluids or contaminated surface waters to enter potable aquifers.

Most of the hundreds of thousands of abandoned water, oil and gas wells, exploration wells, test borings and seismic shot holes in this country have been abandoned improperly. In many cases the existence of the well is not even known. Unfortunately this situation does not appear to be improving significantly nationally. Although most states have regulations to deal with the hazards of well abandonment, they are not uniform and in many cases they do not reflect an understanding of the real problems. Also many states lack enforcement provisions.

Improperly abandoned in situ uranium mining activities have not yet become a problem because no projects have as yet been decommissioned. Restoration and reclamation technology must keep

pace with the in situ solution mining technology so that abandonment will not become a future problem.

This chapter describes environmental impacts of solution mining and makes comparisons with conventional mining when appropriate. Impacts are discussed under the following headings:

- air quality
- land use
- surface water quality
- groundwater quality
- liquid waste

Chapter 4 discusses restoration.

3.1 Air Quality

Solution mining normally has a lessor impact on air quality than conventional mining. Releases to the atmosphere are substantially less than that from a conventional mine-mill complex, since ore is not stockpiled above ground and voluminous mill tailings accumulations are avoided. The sources of impacts on air quality result mainly from:

- construction of
  - -access and service roads
  - -recovery plant
  - -ponds and evaporation pits
  - -well field
- operation and maintenance of
  - -injection, production and monitor wells
  - -recovery plant process equipment, waste ponds and pits

Nonradiological Impacts

Nonradiological impacts on air quality result mainly from construction activities. Fugitive dust and gaseous emissions from construction equipment result from building access and well field service roads, clearing for the process plant, and constructing pond embankments. These effects are small because the activities are of short duration and produce low emission rates. Although service and access roads will be minor sources of fugitive dust, localized degradation of air quality may occur on particularly windy days. Commonly employed dust suppression measures will minimize these impacts.

During operation, air quality can be affected to a small degree by nonradioactive emissions from the uranium recovery process plant and the liquid waste storage and water treatment ponds. These plant emissions include combustion products from uranium oxide (yellow cake) drying units, volatilized leaching solution,

and process solution residuals. Where ammoniacal solutions are used as the principal chemical to dissolve the uranium in the ore, ammonia vapors may be released from the process plant and from the liquid waste ponds. Estimates by the NRC using a point-source dispersion model have shown maximum ammonia concentrations of about 5 mg/m³ at 500 meters (1640 feet) and 75 mg/m³ at 100 m (328 feet) from the plant. These values are well below the occupational threshold limiting value of 35,000 mg/m³, the odor threshold of 37,000 mg/m³, and the lowest atmospheric concentration of 1000 mg/m³ known to affect vegetation. Ammonia would not be a factor, however, if alternate lixiviants were used.

Radiological Impacts

Air emissions occur from surge tank vents in the uranium recovery facility, from drying room stacks, evaporation ponds and other miscellaneous sources. Except for radon-222, these emissions are relatively easy to quantify, based on technology developed for the conventional uranium milling industry. Generally, atmospheric emissions and environmental impacts are projected to less for in situ recovery processes on a production rate basis than for conventional milling activities. Radon-222 emissions have been estimated to be roughly comparable during milling operations. Following abandonment of the wells, radon emanation from mined areas should reduce to essentially zero. Long term radon emanation will continue from mill wastes and evaporation

pond residues and the source term will be determined by the waste disposal and site restoration methods used. While radon appears to be less of an environmental problem with in situ mining as compared with conventional mining, it still represents the largest dose potential through the air pathway and should be carefully evaluated and monitored during in situ activities. Not enough is known about source terms, environmental pathways and biological effects to assess radon impacts with confidence, even with conventional mining and milling techniques. This uncertainty is the principal reason that radon was excluded from EPA's drinking water regulations, and it was also a factor in the decision to exclude radon from EPA's Uranium Fuel Cycle Standard. Because in situ mining of uranium represents a radical departure from conventional experience, radon impacts are even more uncertain. This subject needs much more study. Fortunately this need has been recognized, and many radon studies are in progress by EPA and other Federal and State agencies.

Estimation of annual dose commitments to the nearest residence depends upon exposure to airborne radionuclides and subsequent deposition and saltation mechanics. Local meteorological data are used with a dispersion model to estimate dose. A comparison of annual dose commitments with radiation protection standards is shown in the following example (Table 3-1) for a solution mining project in Wyoming:

Receptor organ	Estimated annual dose commitments	Radiation protection standards	Fraction of standard
	Present NRC Regulation (10 CFR Part 20)		
Total body	6.84E-2 mrem/year	500 mrem/year	1.4E-4
Lung	7.55E-1 mrem/year	1500 mrem/year	5.0E-4
Bone	4.31E-1 mrem/year	3000 mrem/year	1.4E-4
Bronchial epithelium	4.8E-6 WL[a]	3.3E-2 WL[a]	1.5E-4
	Future EPA Standard (40 CFR Part 90)		
Total body	6.84E-2 mrem/year	25 mrem/year	2.7E-3
Lung	7.55E-1 mrem/year	25 mrem/year	3.0E-2
Bone	4.31E-1 mrem/year	25 mrem/year	1.7E-2
Bronchial epithelium	4.8E-6 WL[a]	NA[b]	NA[b]

[a]Radiation standards for exposure to Rn-222 and daughter products are expressed in Working Level (WL). WL means the amount of any combination of short-lived radioactive decay products of Rn-222 in one liter of air that will release 1.3×10^5 mega electron volts of alpha particle energy during their decay to Pb-210.

[b]Not applicable because 40 CFR Part 190 does not include doses from Rn-222 daughters.

Source: NRC, NUREG-0489, 1978

Table 3-1
Comparison of Annual Dose Commitments to the Nearest Resident at 4.5 km (2.8 miles) with Radiation Protection Commitments

In summary, the release of airborne radioactive materials from a solution mining operation is expected to be substantially less than from a conventional uranium mining and milling complex. The sources of airborne radionuclides are primarily the recovery plant, liquid waste ponds and evaporation pits.

3.2
Land Use

The lack of major surface disturbance and absence of large quantities of mine spoils is a singular advantage of solution mining over conventional surface mining methods.

A single solution mining project could restrict usage of several hundred acres over the life of the operation. Because uranium ore deposits are generally located in sparsely populated areas, the number of people affected would be small. Also, all land would not be impacted at once. As an example of the impact on ranching, grazing capacity per animal unit is on the order of less than 10 acres per month in the Powder River Basin of Wyoming. In one project, a 50-acre well field operation would result in a loss of grazing capacity that would support five cows per year(NRC, NUREG-0481, 1978).

Several miles of roads would be improved or new roads would be constructed over the operating life of a project. The roads could provide improved access to specific portions of properties controlled by local ranchers. The project induced traffic on these roads would be small and would not significantly affect ranching activities.

Hunting and off-road recreation would be curtailed during the project life also. The impact would depend upon the general availability of hunting and recreation opportunities in the project vicinity.

Since solution mining disturbs a relatively small surface area, the protection required for cultural, archaeological and historic sites can be provided with relative ease compared to conventional mining practices.

3.3 Surface Water Quality

Surface water can become contaminated during construction activities, during mining operations, or after operations end as a result of improper abandonment. Most uranium in situ activities will likely be designed for zero or very low discharge of contaminated wastes to surface waters. Any surface discharges must be permitted under the NPDES system of the Clean Water Act and must be strictly controlled in accordance with permit conditions. However, in some cases surface waters may receive flows from ground waters through paths that are imperfectly understood. Improperly abandoned wells or test holes nearby can provide one mechanism for this, and in some instances a natural connection may exist between underground aquifers and surface waters. The monitoring system should be designed and operated so as to detect any such commingling of waters.

Flooding, failure of evaporation pond dikes, or seepage through inadequate or failed pond liners are a few of the mechanisms that can result in unplanned releases of contaminants to surface waters during operation. The concerns about surface water contamination can be summarized as follows:

- increased sediment loading from cleared areas and roads
- increased erosion due to rapid runoff
- damage to aquatic life or habitat
- accidental release of contaminants
- degradation of groundwater by pond seepage

Sedimentation and Erosion

The amount of sediment loading to nearby streams is of concern but is expected to be small because very few (less than 100) acres will be disturbed at any one time. The impact of an accidental spill or pipeline rupture is perhaps the greatest concern because of the potentially toxic and radioactive constituents in the various solutions.

Land clearing will increase the potential for erosion and sediment discharge from the site, since runoff will be more rapid on the cleared land. Scouring and erosion of nearby stream channels may be accentuated. Proper grading and drainage design can reduce or eliminate these problems.

Sediment control is a major concern for mine operators. Diversion channels and ponds are used to reduce the impact of severe storms and ensuing runoff on the receiving waters or stream beds. With the enactment of the Surface Mining Control and Reclamation Act of 1977, coal mine operators are responding to non-point source regulation requirements. Provisions similar

to the Act are being considered for mining of other minerals such as uranium. Point source discharges are subject to the National Pollutant Discharge Elimination System (NPDES) permit system since the early 1970's.

For a solution mining operation, sedimentation and erosion effects may be reduced because of the following factors:

- The topography of the drainage area may be relatively flat.
- The soil may exhibit considerable infiltration capacity.
- The precipitation may be intense but relatively low in quantity.
- The disturbed or cleared area may be small in relation to the drainage area.

Contaminated Liquids

The process solutions used for in situ leaching contain radioactive and nonradioactive substances which can degrade groundwater quality if accidentally released. These contaminated solutions contain the chemicals which are intentionally added to the groundwater to produce the lixiviant and products formed by the geochemical reactions between the lixiviant, ore minerals and host rock. Secondary reactions also occur with trace elements in ore deposits. These secondary reactions include slightly soluble salts or ion complexes of molybdenum, selenium, arsenic,

manganese, vanadium, copper, zinc, lead, barium, fluoride, mercury and cadmium (NRC, NUREG/CR-0311, 1978). The geochemical mobility of radium, thorium, radon and radon progeny during and after leaching is not well understood. These decay products are contained in the wastes and must be isolated from surface water and groundwater also.

These liquid wastes may be produced when injection wells are cleaned by reversing flow to remove residual solids from the surrounding formation and the well itself. Some ten well bore volumes may be pumped from the well before injection resumes. Also contaminated process solutions are produced at various steps in the uranium recovery circuit, described earlier. Such wastes result from water softening, resin rinsing, eluant bleed and wash waters. These wastes contain uranium and uranium daughter products including radium and dissolved solids that must be isolated from surface and groundwater.

Table 3-2 gives typical estimates of the liquid waste volumes produced during operation of a 500,000 lb per year uranium oxide facility. The estimated waste volumes do not vary significantly with type of lixiviant used. All wastes are radioactive except sanitary wastes which are discharged to a sanitary waste drain field. Groundwater restoration volumes are not included.

Table 3-2
Annual Liquid Effluent Volumes

Source	Acre feet per year
1. Over production of the well field (1% of design production rate)	14.6
2. Well cleaning to maintain injection flows	5.5
3. Contaminant control of recovery plant process liquids	included in 1
4. Plant and well field sanitary water use	2.1 (a)
5. Monitor well sampling	0.9
Affected volume from mining operations/year (Items 1, 2, & 5)	21.0

(a) Goes to sanitary waste field

Source: Adapted from NRC, NUREG-0481, 1978

Solar evaporation ponds covering six acres could handle the 21 acre-feet of wastes (NRC, NUREG-0481, 1978).

Liquid Waste Disposal

Disposal and/or containment of certain process solutions is a necessary part of operating a solution mining facility. The composition of the liquid waste streams from the uranium recovery process are comparable to conventional mills. Accordingly, careful disposal practices are required.

Following the conclusion of mining operations, depending on the aquifer restoration and well abandonment techniques needed to return the site to an acceptable condition, very large volumes of low-solids liquid radioactive wastes may be produced which will require disposal or treatment. Since restoration methods are still in the development stage for full scale in situ operations, liquid waste volumes are uncertain and could pose serious disposal problems because of their large quantity. Disposal methods which have been suggested include: recycle for irrigation or other limited use in nearby activities, disposal into an injection well, and treatment and discharge to the surface. Any such disposal methods using injection wells will be categorized as Class I or Class IV wells, and will come under other parts of EPA's Underground Injection Control regulations when they become effective. Treatment and discharge to surface waters and irrigation will have to be permitted under the NPDES system established under the Clean Water Act.

Aquatic Life

The potential impact of any mining operation on aquatic life or habitat is subject to site-specific analysis and cannot be generalized. Discharge of sediments, oil and grease and other contaminants, if not controlled, could have an impact on the aquatic environment, affect benthic organisms, and fish spawning areas. Waste discharge control techniques are available to mitigate such impacts.

Accidental Releases

During operation, the potential exists for accidental release of contaminated liquids to the surface water. Above ground piping may rupture or break releasing chemical and radioactive contaminants. Accident analysis and contingency plans are designed to identify such potential failures and to specify actions to be taken to prevent releases to surface or groundwaters. Emergency storage ponds may be required, and contaminated soil removed and disposed of in an approved disposal area.

Pollution control considerations must be included in the design of ponds or systems which process or store toxic elements that could be discharged accidentally on land surfaces and then possibly find their way into the groundwater system.

3.4 Groundwater Quality

Projected solution mining operations will occur mainly in water scarce regions of the western states where the principal uses of groundwater are domestic use, livestock watering, and municipal supply for small communities. Degradation of groundwater quality is of great concern to groundwater users in these regions. During mining the consumptive use of groundwater is small compared to that required for restoration after mining operations cease. The potential impacts of concern are degradation of groundwater adjacent to the ore zone and consumptive water use

during mining and restoration. This is a most worrisome impact because of the inherent limitations in any attempt to characterize local hydrologic and geologic features and to anticipate future process alterations by the mineral extraction industry.

Natural Groundwater Quality

Natural groundwater adjacent to ore zones in Wyoming and the Colorado Plateau (parts of Colorado, Utah, Arizona and New Mexico) generally contains total dissolved solids (TDS) ranging from 160 to 1250 milligrams per liter (mg/1). The majority of the dissolved salts are calcium or sodium sulfates or bicarbonates (NRC, NUREG/CR-0311). Since the EPA National Secondary Drinking Water Standards specify a maximum TDS level of 500 mg/1 and Wyoming Livestock Water Quality Criteria specify 5000 mg/1, these groundwaters are potential sources of potable and agricultural water. Groundwater in contact with uranium ore bodies exhibit radioactivity that is greater than acceptable limits, but in general, heavy metal concentrations are within public health standards.

During pilot-scale testing, at the Irigaray Project, groundwater sampled at distances of a few hundred feet from the ore zone generally met drinking water standards, but groundwater in the ore zone generally exceeded drinking water standards for radium, uranium and gross alpha (NRC, NUREG-0481, 1978).

Groundwater Consumption

Although consumption of groundwater during mining is small compared to conventional mining, withdrawal of groundwater over extended periods of time can temporarily affect the level of the water table adjacent to the ore zone and the overlying alluvium. The impact of groundwater withdrawal depends upon the hydraulic connection between the ore zone and alluvium. Groundwater users could be affected during mining and until the natural water table is returned to its premining level. Restoration, discussed in Chapter 4, requires greater volumes of groundwater and represents the largest consumptive use, approximately 20 to 30 times that required during mining.

Lixiviant Excursion

Excursion of lixiviant outside the ore zone would degrade groundwater quality at least temporarily until the lixiviant was recovered by pumping or until sufficiently diluted by uncontaminated groundwater.

The effect of an excursion on groundwater quality is displayed in Table 3-3. The changes were detected during a confirmed lateral excursion in south Texas. Ammonium bicarbonate was used as the lixiviant.

The best indicator that the excursion took place was the increase in calcium, magnesium, sodium, chloride and sulfate (shown in the table). In this example, surrounding groundwater was impaired

Table 3-3

Changes in Selected Water Quality Parameters Due to Excursion

Large Increase	Moderate to Large Increase	Moderate Increase	Very Small Increase
Specific Conductivity	Magnesium	Sodium	Bicarbonate
Calcium	Boron		
Chloride			
Sulfate			
Manganese			
No Measurable Change			
Fluoride	Mercury	Uranium	
Ammonia	Molybdenum	Vanadium	
Cadmium	Nickel	Nitrate	
Chromium	Selenium		
Copper	Silver	Zinc	
Inconsistent Lab Results			
Radium	Iron		
Arsenic	Lead		
Barium			

Source: Adapted from NRC, NUREG/CR-0311

only by an increase in total dissolved solids. No hazardous or toxic material was detected that would impair use of the surrounding groundwater as a supply of drinking water.

Water level monitoring is recommended (NRC, NUREG/CR-0311, 1978), as an indicator for developing lateral lixiviant excursions rather than relying on water quality data as the only indicator to confirm the occurrence. The excursion discussed in the

previous example was caused by an injection-production imbalance. Excess injection in mining areas created a hydraulic gradient away from the well field to adjacent monitor wells. Had corrective action been taken to restore the injection-production balance as the rise in water levels began, the excursion might not have reached the monitor wells.

If a lateral excursion is extensive, then procedures identical to restoration may have to be applied. The difficulty is that the excursion may continue beyond the influence of any available wells in the well field. The importance of early detection by water level monitoring is essential in preventing a single excursion from developing into a full scale restoration program.

3.5 Solid Wastes

Both radioactive and nonradioactive solid wastes are generated during solution mining. These wastes are not as varied or as large as those generated by conventional mining. EPA has proposed disposal criteria for all categories of radioactive wastes as the initial step of the Agency's Standards development efforts. These criteria have been sent to the President for his concurrence and issuance as FRC guidance to Federal agencies.

Sources of solid wastes vary from project to project but generally include:

- Materials trapped by filters in injection well lines
- Sediments in surge tanks
- Spent resin used in the uranium recovery plant
- Solids deposited in evaporation ponds
- Salts from water treatment facilities
- Trash expendables or residue from operations
- Sanitary wastes

The chemical nature and amounts of the wastes are dependent on the ore body, the minerals that are mobilized by the leaching solution (the lixiviant), the uranium recovery process and in some instances the treatment methods applied to solutions recovered from the process and reinjected.

The largest volume of solid waste produced during solution mining is due to removal of calcium from the lixiviant. Calcite, natural calcium carbonate, in the ore zone may be dissolved by the lixiviant and cause plugging of the injection and production wells and reduce the efficiency of the ion-exchange process.

Calcium can be removed by precipitation of calcium carbonate from alkaline lixiviants and calcium sulfate ($CaSO_4$) from acid lixiviants prior to reinjection. At one site in Wyoming, it is estimated that two pounds of calcium carbonate are produced for each pound of uranium oxide recovered. However, other contaminants including radium-226 are also removed during the calcium precipitation. The secondary benefit of calcium removal

is that about 95% of the radium-226, mobilized by the lixiviant, is removed prior to reinjection (NRC, NUREG-0481).

The long-term objective of solid waste disposal is to isolate the radioactive wastes from the environment and reduce exposure from radiation. Solids contained in slurry form or waste solutions may be temporarily deposited in a lined evaporation pond at the project site during operations. The slurry and solution contains radioactive uranium and other naturally occurring radioactive materials. To reduce particulate emissions and radon gas emanation into the atmosphere, a liquid seal is required to cover the pond. Ultimately, the radioactive solids must be disposed of in a licensed active uranium mill tailings disposal and retention site or other licensed disposal facility. Nonradioactive wastes can be disposed of at a licensed burial site or the tailings facility. Sanitary wastes are subject to state sanitation requirements.

Chapter 4

Restoration of Groundwater Quality

Injection of lixiviant into the ore zone has the potential to significantly increase the concentration of toxic and radioactive constituents in the groundwater. The most important problem facing the developers and regulators of solution mining projects is to restore groundwater quality to acceptable levels after leaching operations are discontinued.

Considerable research is in progress to improve the restoration process, but the current level of technology requires operators to remove and treat large quantities of water. The cost of this treatment process frequently approaches the capital invested in the uranium recovery plant. In this chapter of the guide, restoration criteria will be presented, restoration methods will be discussed, and the wastes generated from the restoration process will be described.

4.1
Criteria for Restoration

It is generally recognized that two classifications or zones of groundwater are contained within the boundaries of a solution mining project. These zones are (1) the groundwater surrounding the ore zone, and (2) the groundwater within the ore zone. Accordingly, the NRC, EPA, and states have established different criteria for restoring the water in the two zones.

Groundwater Surrounding the Ore Zone

If the water contained in the area surrounding the ore zone is suitable drinking water for humans or livestock, the regulatory agencies require restoration to these potential uses. The allowable concentration of various constituents is summarized in Table 4-1. The list of constituents reported in the table is restricted to those substances which might be encountered by a typical solution mining operation.

Restoration of the groundwater in this area does not represent any particular problems to the in situ leach operator, if the injected leaching solutions do not contact the surrounding formations. The operator minimizes the potential for accidental solution migration by recovering more water from the well field than is injected. This causes water in the surrounding aquifers to flow towards the leaching zone rather than allowing the lixiviant to flow towards the uncontaminated water.

All units in mg/liter, unless indicated otherwise

Parameter	Wyoming DEQ water quality criteria for wildlife and livestock[a]	NAS criteria for irrigation water[b]	Recommended limit for protection of aquatic life	Drinking water standard	Toxic Concentration[c]	
					Mean toxic concentration[d]	Lowest toxic concentration[e]
NH_3[f]			0.02[b,g] (for un-ionized ammonia)	0.5[h]		
Cl^-	2000			250[i,j]		
SO_4	3000			250[i,j]		
Ag				0.05[i,k]		
Al	5.0		5.0		18.9	0.07
As	0.2	0.1		0.05[i,k]	13.6	0.022
B	0.5	0.75			900	0.69
Ba				1.0[i,k]	1080	8.0
Cd	0.05		0.003-0.03[b,g] 0.001-0.012[g] (for hard water)	0.01[i,k]	7.4	0.0009
Co		0.05			21	0.021
Cr	1.0	0.1	0.05[b]-0.1[g]	0.05[i,k]	80.7	0.008
Cu	0.5	0.2		1.0[i]	1.6	0.006
Fe		5.0	1.0[g]	0.3[j]	1235	0.02
Hg	0.01		0.05[g]	0.002[k]	0.2	0.003
Mn		0.2		0.05[i]	2259	17
Mo		0.01			147	47
Ni		0.20		1.0[l]	13.0	0.05
Pb	0.1	5.0	0.03[b]	0.05[k]	69.8	0.007
Se	0.05	0.02		0.01[k]	11.2	1.0
U					36.2	1.7
V		0.1			27.3	4.8
Zn	25	2.0		5[j]	7.9	0.0001
F	2.0	1.0		0.7-1.2[i]		
Total dissolved solids	5000			500[i,j]		
pH	6-9			6.5-8.5[j]		
Ra-226; pCi/liter				5.0[j]		
Gross α, pCi/liter				15.0[j]		
Gross β, pCi/liter				1000.0[i]		

[a]Data obtained from Wyoming Department of Environmental Quality, Land Quality Division, Guideline No. 4 (Revised), Nov. 9 1976, p.3-41.

[b]Data obtained from National Academy of Sciences, Environmental Studies Board, Water Quality Criteria 1972, EPA/R3/73-033, March, 1973.

[c]R. M. Cushman, S. G. Hildebrand, R. H. Strand, and R. Anderson, The Toxicity of 35 Trace Elements in Coal to Freshwater Biota: A Data Base with Automatic Retrieval Capabilities, Report ORNL/TM-5793, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1977.

[d]Mean of all concentrations (ppm) found to be lethal to fish in experiments lasting 96 hr or longer.

[e]Lowest concentration (ppm) found to be lethal to any aquatic organism.

[f]The toxicity of ammonia is discussed in detail in the text.

[g]Data obtained from U.S. Environmental Protection Agency, Quality Criteria for Water, EPA 440/9-76-023, 1976.

[h]Data obtained from World Health Organization, European Standards for Drinking Water, Geneva, Switzerland, 1961.

[i]Data obtained from U.S. Public Health Service, Drinking Water Standards, PHS Publication 956, 1962.

[j]Data obtained from "Proposed National Secondary Drinking Water Standards," Fed. Regist. 42(62): 17143-17147 (March 31, 1977 1977).

[k]Data obtained from "National Interim Primary Drinking Water Regulations," Fed. Regist. 40(248): 59566-59577 (Dec. 24, 1975).

[l]Data obtained from T. Kirkor "Protecting public waters from pollution in the USSR" Sewage Ind. Wastes, 23(7): 938-940 (1951).

Source: NRC, NUREG-0481, 1978

Table 4-1

Water Quality Criteria and Toxic Concentrations for Potential Contaminants from Solution Mining

Groundwater Within the Ore Zone

Table 4-2 shows baseline water quality in three uraniferous aquifers. By comparing these concentrations to the allowable concentrations in Table 4-1, it is obvious that the groundwater contained in the mineralized portion of the aquifer is naturally contaminated with high concentrations of uranium, radionuclides, dissolved solids, etc. and is not suitable for domestic use or livestock consumption.

Because of this natural contamination, the NRC has indicated that returning the ore zone water to within 20% of baseline conditions is adequate (NRC, NUREG-0481, 0489, 1978). However, as indicated by the information presented in Table 4-3, the residual concentration of certain components in the leached-out aquifer is several times greater than baseline. Therefore, accomplishing the restoration objective may require costly measures.

4.2
Restoration Methods

Pilot-scale restoration efforts have been conducted at several operations. However, because the pilot plant is typically surrounded by the ore body in contrast to production operations which may extend to the limits of the ore body, the results of such studies cannot be extrapolated to the entire well field with a high degree of confidence. Also because restoration is site specific, a method successfully applied at one property may not suffice at another location.

Constituent	Concentration		
	Irigaray	Exxon-Highland	Texas*
Arsenic, ppm	<0.0025	0.0015	-
Barium, ppm	0.12	-	-
Boron, ppm	0.16	0.02	-
Cadmium, ppy	<0.005	0.002	-
Chromium, ppm	0.0135	<0.001	-
Copper, ppm	0.019	<0.001	-
Fluoride, ppm	-	0.2	-
Lead, ppm	0.0035	0.002	-
Manganese, ppm	0.12	-	-
Mercury, ppm	0.0028	<0.0001	-
Nickel, ppm	0.018	-	-
Selenium, ppm	0.013	<0.001	-
Silver, ppm	<0.005	-	-
Zinc, ppm	0.003	0.007	-
Uranium as U_3O_8, ppm	0.098	0.095	0.119
Ammonia, ppm	<1.0	-	1.29
Chloride, ppm	10.75	27	369
Bicarbonate, ppm	139	237	258
Total dissolved solids, ppm	793	-	1013
Sulfate, ppm	-	119	119
Radium 226, pC_1/Liter	26.8	120-470	-
Thorium, pC_1/Liter	-	86	-
Calcium, ppm	-	77	79
Sodium, ppm	-	161	235

* Average from 4 sites in Texas, adapted from Kasper and Engelmann, 1978

Sources: NRC, NUREG-0481, -0489, 1978

Table 4-2
Baseline Water Quality in Various Uraniferous Aquifers

COMPONENT	AMMONIUM BICARBONATE LIXIVIANT	SODIUM BICARBONATE LIXIVIANT	CALCIUM OR MAGNESIUM BICARBONATE LIXIVIANT
NH_4 (ppm)	500 - 3,500	(Baseline)	(Baseline)
Ca (ppm)	100 - 500	100 - 500	100 - 700
Mg (ppm)	20 - 200	20 - 200	< 1,500
Na (ppm)	200 - 2,000	1,000 - 3,500	200 - 2,000
K (ppm)	20 - 100	20 - 100	20 - 100
(CO_2) (ppm)	—	—	< 2,000
HCO_3 (ppm)	1,000 - 10,000	1,000 - 10,000	1,000 - 10,000
Cl (ppm)	500 - 3,500	500 - 3,500	50 - 500
SO_4 (ppm)	200 - 1,000	200 - 1,000	200 - 1,000
U_3O_8 (ppm)	5 - 40	5 - 40	5 - 40
Ra-226 (pCi/l)	200 - 1,700	200 - 1,700	200 - 1,500
pH	6.5 - 9.0	6.5 - 9.0	6.0 - 8.5

Source: Wyoming Minerals Corp., 1978

Table 4-3
Typical Compositions of Residual Lixiviants (in depleted formation after it has been mined-out but before restoration of groundwater quality begins)

Because of these complexities and the inherent difficulties associated with restoration, this aspect of solution mining is receiving the greatest attention. Restoration techniques that have been attempted or proposed include:

- Groundwater sweeping
- Groundwater sweeping in combination with treating the groundwater in preparation for reinjection.
- Natural restoration

Each technique is discussed in the paragraphs that follow.

Groundwater Sweeping

Groundwater sweeping was the first concept considered for restoration. The method involves pumping groundwater from selected wells after the leaching cycle has been completed. The pumping is intended to draw water from outside the leaching zone and displace the contaminated solution. The contaminated liquor is then placed in impoundment basins.

This technique has been evaluated by virtually all solution mining operators, but the most recent data was presented by Exxon and Wyoming Minerals for their proposed operations in Wyoming. Exxon is proposing to use a sodium bicarbonate lixiviant while

Wyoming Minerals intends to employ ammonium bicarbonate as the leaching agent.

The results of groundwater sweeping tests perrormed by Wyoming Minerals at Irigaray were not encouraging. After removing several thousand gallons of water from a single test well, the concentration of certain constituents in the groundwater was still several times greater than baseline. As anticipated, the level of ammonia was not reduced significantly. The chemical analysis of the groundwater at the beginning and upon completion of the sweeping test is presented in Table 4-4.

Despite these discouraging results, examination of this data reveals that groundwater sweeping was effective in reducing the concentration of certain substances - particularly the total dissolved solids content. However, restoration by groundwater sweeping only cannot be considered as an effective technique, since tremendous quantities of water are required to flush the contaminants from the ore zone. Although the quantity of water is less than the process water requirements for a conventional mill, the cost of the evaporation ponds required to contain the contaminated well field solution would be prohibitive.

The Highland solution mining project of Exxon is a notable exception to the above. Based on the results of the pilot scale groundwater sweeping tests, Exxon projected the groundwater would be restored to near baseline conditions after withdrawing approximately 450 gallons a minute from the aquifer over a period

	Initial (ppm) [1]	Final (ppm)	5I7 Baseline [2] (ppm)
NH_4	180	123	< 1.0
As	.033	.017	< .0025
Ba	.09	.03	.12
B	8.3	0.26	.16
Cd	0.30	< .002	< .005
Ca	58.5	13.5	---
CO_3	4.2	4.7	---
Cl	531	229.9	10.75
Cr	< .002	.004	.0135
Cond (µmhos)	3.30×10^3	1.95×10^3	---
Cu	.215	.041	.019
F	2.75	4.10	---
$CaCO_3$	616	445	232
Fe	2.15	.65	---
Pb	.32	0.58	.0035
Mg	19.5	5.4	---
Mn	.784	.150	.12
Hg	.0002	< .0002	.0028
Mo	< .02	.42	---
Ni	1.79	< .20	.018
NO_3	4.92	1.24	---
NO_2	2.76	0.151	---
pH	7.94	8.14	---
K	8.14	2.9	---
Se	1.02	.339	.013
Si	5.3	3.3	---
Ag	< .002	< .002	< .005
Na	308	210.8	---
SO_4	270	233	---
TDS	1,302	712	793
V	< .05	.21	---
U_3O_8	18	12.3	.098
Zn	.218	.02	.003
Ra-226 (pCi/l)	478 ± 9	105 ± 10	26.8 ± 5.2
Gross Alpha "	12,317 ± 288	5,412 ± 177	168 ± 11
Gross Beta "	5,374 ± 115	2,052 ± 85	164 ± 19
Th 230 "	640 ± 21	1.5 ± 0.9	---

[1] Values in ppm, except pH and as otherwise noted.

[2] Original 5I7 baseline values were determined on a single sample analysis and did not include all parameters of interest.

Source: NRC, NUREG/CR-0311, 1978

Table 4-4

Water-Quality Changes Resulting from Ground-Water Sweep, Irigaray 517-3 Pilot

of 6 years. On this basis, approximately 1.5 billion gallons of groundwater would be removed from the ore zone which is equivalent to moving 7 pore volumes of solution through the aquifer. As previously mentioned, the costs associated with impounding this quantity of water on the surface would be excessive. However, Exxon plans to pump the contaminated solution to their existing mill, thus providing approximately 50% of their conventional process water requirements. This situation is currently unique to the solution mining industry.

It has been suggested adding calcium, magnesium, or potassium to the "sweep" solutions to expedite desorption of ammonia from the clays. The results of field experiments suggest that this practice substantially increases the ammonia desorption rate initially, but as restoration progresses and the solutions begin to reach equilibrium, the rate of the ion exchange reactions decrease. Others suggest using bacteria to sustain an increased desorption rate of ammonia and heavy metals. Also proposals have been made to add chemicals to the restoration liquors to reduce the valence state of certain complexes and precipitate insoluble compounds. Potential reducing agents include sodium sulfide and hydrogen sulfide. These concepts warrant further investigation.

There are three principal reasons why groundwater sweeping alone is only partly successful (NRC, NUREG/CR-0311, 1978). These reasons are:

- The permeability of uraniferous sandstones is extremely variable. Thus, inflowing groundwater will preferentially sweep through established channels. As restoration continues, water that was originally bypassed will be slowly removed.
- Certain constituents in the lixiviant are adsorbed by the clays present in the formation. Without stimulus (chemical, bacterial, etc.), the desorption process is extremely slow.
- The water contained in the aquifer prior to leaching has probably reached chemical equilibrium with the formation. Leaching disturbs this equilibrium and it will undoubtedly be difficult to reestablish it within a reasonable time span.

Groundwater Sweeping and Treatment

This technique involves removing certain dissolved salts from the solution recovered from groundwater sweeping and reinjecting the treated water to continue the sweeping process. In so doing, the amount of water that must be impounded on the surface or disposed of is substantially reduced.

Several water treatment methods have been proposed but reverse osmosis (RO) is being considered or tested for most solution mining projects. In RO pressure is used to force the diffusion of pure water selectively through a semipermeable membrane in contact with the solution.

The results of RO field test at Wyoming Minerals' Irigaray site are outlined in the Table 4-5.

Constituent	Concentration of constituent in mg/l		
	Before reverse osmosis	After reverse osmosis	Percent Reduction
U_3O_8	43	< 1	> 97.6
CO_3	8	< 4	> 50.0
Cl	686.8	26	96.2
SO_4	641.8	4.3	99.3
Na	434	10.7	97.5
Ca	71.5	2.2	96.9
Mg	23.3	< 1.0	> 95.7
NH_4	54.3	2.7	95.0

Source: Adapted from NRC, NUREG/CR-0311, 1978

Table 4-5
Effectiveness of Reverse Osmosis in Wyoming Minerals Irigaray Project

Approximately 80% of the solution fed to the RO unit was recovered as product water suitable for reinjection. The remaining 20% or reject solution containing most of the dissolved salts would be impounded in evaporation ponds. Compared to groundwater sweeping without treatment, reinjection of RO treated water will effect a five fold decrease in the amount of water which must be evaporated or disposed of.

RO is not without problems, however. The membranes are sensitive to fouling due to precipitation of salts, other suspended solids, and bacterial and chemical degradation. Accordingly, the solution may need to be treated prior to being fed to the RO units. This pretreatment is expected to consist of chlorination, softening/clarification, filtration, pH control, and chemical addition to inhibit formation and precipitation of scale. Even with such elaborate pretreatment systems, RO membrane life expectancy will be less than 3 years.

To increase the effectiveness of the sweep-treatment restoration process, several operators have proposed adding certain ions to the product water to expedite desorption of ammonia from the clays. Calcium and magnesium are excellent candidates, because their affinity to certain clays has been demonstrated (NRC, NUREG-0481, 1978). Unfortunately, increasing the concentration of these elements not only increases the ammonia desorption rate, but also increases pretreatment costs. Calcium and magnesium compounds have low solubilities and could foul RO membranes if these chemicals were not effectively removed during pretreatment.

Natural Restoration

Allowing the aquifer to "heal" itself may have particular merit in uranium solution mining. Under the proper circumstances, most of the objectionable elements which were mobilized during leaching might be removed by natural reprecipitation, ion exchange, adsorption, or reduction (NRC, NUREG/CR-0311, 1978). Unfortunately, the concept of natural restoration has not been studied in the field but as the solution mining industry progresses, pertinent data should become available.

To summarize, simple groundwater sweeping is not expected to play a major role in aquifer restoration except where in situ leaching is conducted adjacent to an existing conventional mill owned by the same company. The contaminated water from the restoration process can then be used to supply a portion of the mill's process water requirements. In situ projects scheduled for production in the near future will undoubtedly use a combination of groundwater sweeping coupled with RO. The RO feed water is expected to be treated, and for ammoniacal lixiviants certain chemicals will probably be added to the product water to stimulate ammonia desorption. The rejected solution from RO will most likely be impounded in evaporation ponds. If research efforts currently in progress stimulate further interest in lixiviants other than ammonia, the restoration process may well be simplified.

4.3
Restoration Wastes

The restoration process will consume a greater quantity of groundwater than the solution mining process. Because the restoration solutions will be contaminated with non-radioactive and radioactive substances, treating or disposing of these solutions represents a significant environmental consideration.

The precise composition and quantity of restoration solutions will depend on the lixiviant employed and the method used to restore the aquifer. Obviously, the restoration process proposed by Exxon-Highlands (NRC, NUREG-0489, 1978) will not generate any waste with which the solution mining operation must contend, since the restoration solutions will be used to supply a portion of the process water required by the conventional mill. As previously mentioned however, this situation is currently unique in the industry and groundwater sweeping alone will undoubtedly play a minor role in future restoration efforts.

It is assumed that restoration will be accomplished by a combination of groundwater sweeping and solution treatment, then the restoration process will generate three basic waste streams. These waste streams are:

- Solids precipitated or filtered from the restoration solution prior to entering the RO circuit.
- The "reject" solution from the RO unit.

- Salts which precipitate from the "reject" solution.

Effective operation of the RO depends, in part, on the clarity and chemical composition of the feed solution. Filtration is normally employed to remove suspended particles from the solution while precipitation and/or water softening techniques are used to remove dissolved constituents which are deleterious to the RO process. In the latter category, calcium is most common (see discussion on pg 3-11) and accounts for the majority of the solids removed from the stream prior to RO. However, the total amount of lime sludge generated is rather insignificant when compared to the tailings from a conventional mill. This lime sludge can easily be impounded in evaporation ponds constructed for the "reject" solutions.

The absolute quantity of solution rejected from the RO unit will vary with the size of the operation and the chemical composition of the groundwater. Generally however, most solution mining developers and operators have estimated that the aquifer must be flushed with 3-5 pore volumes of solution to accomplish restoration by the groundwater sweeping - solution treatment method. Also, data collected by various investigators indicates that RO is capable of producing 4 gallons of "clean" water from every 5 gallons of feed solution (80% recovery). Using these generalizations, it is then possible to estimate the quantity of

waste solution that a RO circuit would produce during the restoration process.

For example, the pore volume of a 50 acre well field with a porosity of 28% and an ore zone thickness of 50 feet would be as follows:

Pore volumes = 50 acres x 50 feet x .28 = 700 acre feet.

Assuming the aquifer must be flushed with 5 pore volumes to achieve restoration, then the total feed to the RO plant would be 3500 acre feet. The RO unit would recover approximately 80% of this solution for continued restoration. The balance, 700 acre feet, might be disposed of in deep wells but most likely, this reject solution would be placed in evaporation ponds.

The above example was intentionally oversimplified. In practice, the leaching-restoration processes would be phased in such a manner that the first pore volume of solution withdrawn from a leached-out well field would be regenerated with reagents and used for leaching a new well field. Similarly, the groundwater displaced from the new field would be used in restoring the aquifer. Thus, the amount of solution that must be impounded in evaporation ponds is somewhat less than the amount indicated above. It should be noted, however, that because the evaporation ponds will contain a high level of dissolved salts, the evaporation rate may be significantly less than that for natural groundwater.

Obviously, if the reject solutions are placed in evaporation ponds, the solutions then become an interim waste product. As the water evaporates, the dissolved salts precipitate. Based on tests performed at Irigaray, Wyoming Minerals estimated the solution rejected from the RO circuit would contain 15 grams of dissolved salts per liter including compounds such as ammonium chloride and sodium sulfate. The solution would also contain radium (greater than 100 pC./liter) and small quantities of uranium, calcium, magnesium, selenium, arsenic, etc. Based on these concentrations, the NRC estimated that 4200 tons of solid waste would result from evaporating the reject solution produced during restoration of a 10 acre well field. These solid wastes will be subject to regulations governing the disposal of conventional uranium mill tailings and other radioactive materials under the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604).

Chapter 5

Regulations and Permits

Numerous federal and state laws and environmental regulations apply to uranium mining projects. The laws, regulations and permitting process for a solution mine are nearly identical to that for a conventional uranium mine and mill. The laws, regulations and approvals that are unique to solution mining are emphasized in this section. An operator must review the entire set of laws and regulations for applicability to his proposed project.

5.1 Generally Applicable Federal and State Laws

Federal laws that must be considered include:

- Atomic Energy Act - 1954
- National Environmental Policy Act - 1969
- Clean Air Act - 1970 and amendments
- Safe Drinking Water Act - 1974
- Resource Conservation and Recovery Act - 1976

- Toxic Substances Control Act - 1976
- Clean Water Act - 1977

The NRC and EPA are the principal agencies responsible for setting and implementing regulations and standards associated with each Act. Through permits and licenses, these agencies control and approve project construction, operation, decommissioning and reclamation activities.

Other federal laws designed to protect man and the environment are:

- Mine Safety and Health Amendments Act - 1977
- Occupational Safety and Health Act - 1970
- Hazardous Materials Transportation Act - 75
- Fish and Wildlife Coordination Act - 1965
- Endangered Species Act - 1973
- Soil and Water Resources Conservation Act - 1977
- Surface Mining Control and Reclamation Act - 1977

State laws in many instances were enacted in response to federal requirements. Legislation at the state level establishes the framework necessary to implement a variety of regulatory programs. As an example, Wyoming has enacted the following laws

applicable to construction and operation of energy related and industrial facilities:

- Wyoming Environmental Quality Act - 1973 as amended
- Wyoming Air Quality Act - 1967
- Wyoming Administrative Procedures Act

These laws served as the authority for:

- Water Quality Standards for Wyoming
- Wyoming Air Quality Standards and Regulations
- Wyoming Land Quality Rules and Regulations
- Solid Waste Management Rules and Regulations
- Regulations For Permit to Construct, Install or Modify Public Water Supplies and Wastewater Facilities in Wyoming

Another important law in Wyoming is the Industrial Development Information and Siting Act of 1975. Under this Act, the Industrial Siting Council is responsible for issuance of permits for construction and operation of industrial facilities, including energy generating or conversion plants. For example, a uranium facility capable of producing 500 pounds of uranium oxide per day would require a permit from the council.

5.2
Regulatory Responsibilities

The NRC has primary responsibility for administration, control and licensing of facilities that process and concentrate uranium. By authority of 10 CFR Part 40, an NRC source materials license is required to "receive title to, receive, possess, use, transfer, deliver...any source material..." i.e., uranium and/or thorium in any form, or ores containing 0.05% or more by weight of those substances.

Agreement and Non-Agreement States

By agreement, licensing authority can be delegated to states having NRC approved programs. In "agreement" states with licensing authority, a state radioactive materials license is required in place of an NRC source materials license. Full environmental impact statements, required under NEPA in a non-agreement state, will not necessarily be prepared in all agreement states.

The map, Figure 5-1, shows the "agreement" and "non-agreement" states. Wyoming is a non-agreement state and Colorado, Texas and New Mexico are agreement states that have solution mining projects.

Agreement states have their own programs which vary from state to state and with non-agreement state procedures. New Mexico and Colorado, two uranium producing agreement states, do not have a

Source: Kasper and Engelmann, 1978

Figure 5-1
Agreement and Non-Agreement States

formal NEPA EIS procedure for licensing uranium mills but require some environmental information in support of the radioactive materials license.

The State of Wyoming is used in this Guide to illustrate the relationship in a non-agreement state between federal and state licensing and permit responsibilities. The Wyoming State Department of Environmental Quality administers the State's Environmental Quality Act of 1973 and is responsible for implementation of the rules and regulations. The key permits for a solution mine producing a U_3O_8 slurry for subsequent processing (drying and packaging) at a conventional uranium mill adjacent to the solution mine operation are listed in Table 5-1.

Permits or license	Granting authority
Source material license amendment	NRC[a]
Mining permit amendment	WDEQ-LQD[b]
Permit for plant construction	WDEQ-AQD[c]
Permit to appropriate groundwater	WSE[d]
Permit for construction of an impoundment (evaporation pit)	WSE, SDEQ-WQD[e]
Operating permit (to be obtained after startup)	WDEQ-AQD
Permit for water supply system	WSBH[f]
Permit for sanitary sewer system	WSBH, WDEQ-WQD
County permit for building	CC[g]

[a]U.S. Nuclear Regulatory Commission.
[b]Wyoming Department of Environmental Quality-Land Quality Division.
[c]Wyoming Department of Environmental Quality-Air Quality Division.
[d]Wyoming State Engineer.
[e]Wyoming Department of Environmental Quality-Water Quality Division.
[f]Wyoming State Board of Health.
[g]County Commissioner, Converse County.

Source: NRC, NUREG-0489, 1978

Table 5-1
Regulatory Approval and Permits Required Prior to Initiation of the Proposed Solution Mining Project

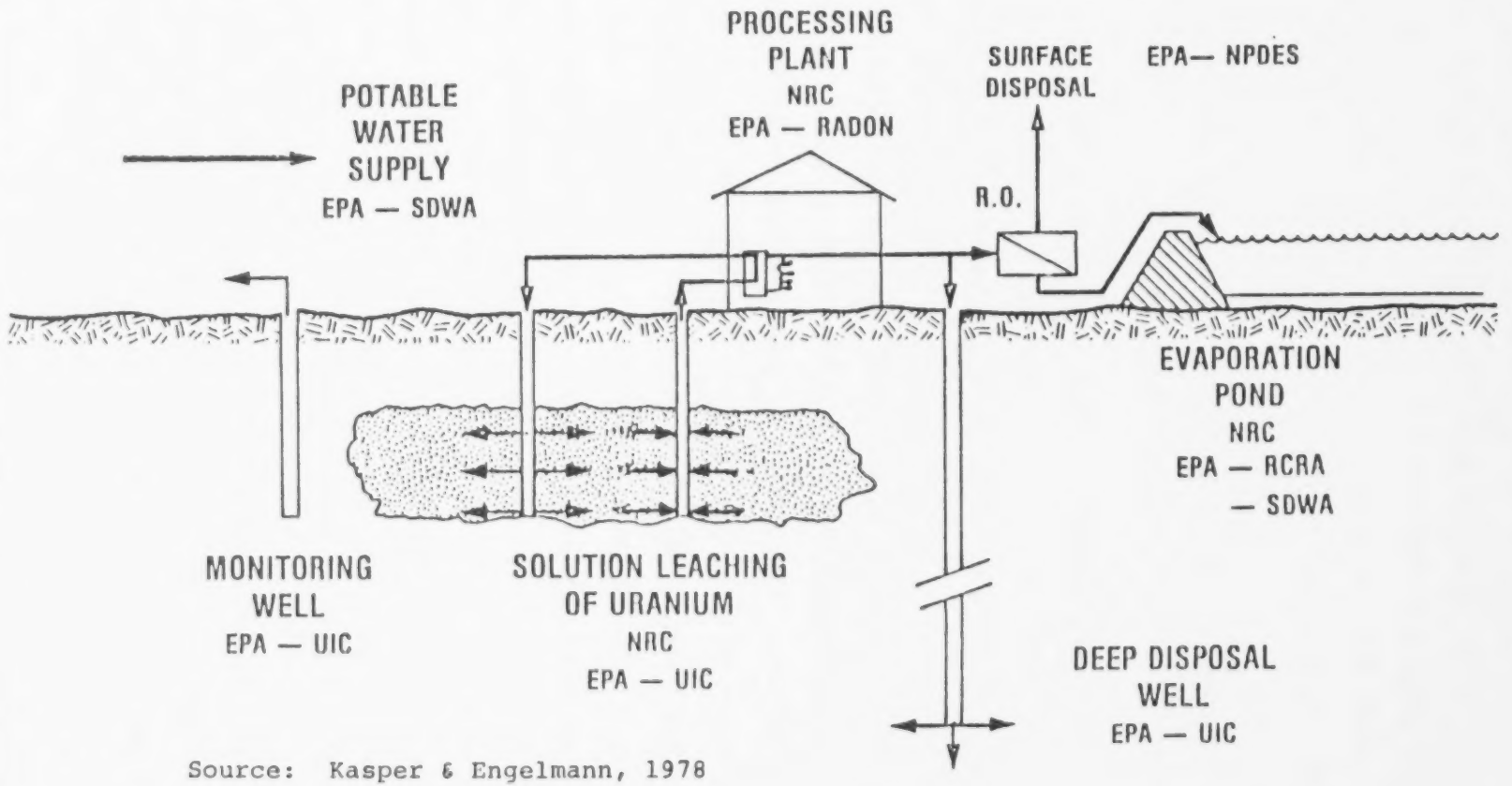
In this example, the NRC source material license and state mining permit amendments regulate solution mine construction and operation. The information required by the NRC is specified in NRC Regulatory Guide 3.5, Standard Format and Content of License Applications for Uranium Mills and NRC Regulatory Guide 3.8, Preparation of Environmental Reports for Uranium Mills. The state requires detailed information in accordance with the Applications for In Situ Permit to Mine which requires a detailed reclamation plan, specific well field monitoring programs and groundwater restoration. The state also requires performance

bonds for reclamation and groundwater restoration. As indicated previously for some new projects, the Wyoming Office of Industrial Siting may require an application for an Industrial Siting Permit. Other federal and county agencies may be involved in approval of rights-of-way for access roads and power transmission lines.

Federal Jurisdictional Responsibilities

Figure 5-2 shows Federal agency jurisdictional responsibilities as they apply to solution mining activities. Figure 5-2 depicts the lixiviant injected into the ore zone and pumped through the formation and to the surface process plant by the recovery wells. Options for disposal of the process wastes are shown. The wastes (described earlier) result from bleeding off the lixiviant to prevent salt accumulation in the leaching circuit and also from the ion exchange recovery process circuit. The waste stream produced is disposed of in deep disposal wells or above ground. Different levels or types of treatment prior to disposal may be required. A reverse osmosis unit and evaporation pond are shown as the alternate disposal system. The reverse osmosis system concentrates the dissolved constituents into a brine which is evaporated in a lined pond. The system also produces good quality water which can be stored on the surface or used in processing.

The EPA is concerned with establishing radiation protection standards that apply to radiological releases from the plant.



Source: Kasper & Engelmann, 1978

Figure 5-2
Regulation for Uranium Solution Leaching by Federal Agencies

Other operations that involve both the NRC and EPA include injection of the leaching solution underground, and impoundment of solution above ground. EPA, by authority of the Clean Water Act and the Safe Drinking Water Act have jurisdiction over point source discharges to the environment and water supplies. Discharges are subject to NPDES permit requirements and water supplies are controlled by drinking water standards.

EPA's National Interim Primary Drinking Water regulations became effective in June, 1977, and establish stringent drinking water limits on many of the same chemical elements and radionuclides present in the lixiviant and in natural geologic structures in the vicinity of typical in situ operations. These regulations provide the limiting values for any discharges which may end up in public drinking water supplies. EPA has now proposed National Secondary Drinking Water Regulations. While the primary regulations cover chemicals and other parameters having public health implications, the secondary regulations cover those having primarily an aesthetic impact. Primary regulations have the force of law and are enforced by EPA or by the States through the "primacy" arrangement. Secondary regulations are not Federally enforceable but are intended as guidelines for the States, which may legislate enforceable standards if they so choose.

EPA has also published (EPA-440/9-76-023, Quality Criteria for Water, July 1976) suggested criteria for quality of water that will establish acceptability for agricultural and industrial uses. These criteria were developed because such criteria were

not available when needed to form the basis for judgment in several EPA and State programs associated with water quality considerations. These criteria were not proposed as absolute values to judge water quality, and are subject to revision as more is learned about the impacts of various contaminants. The criteria are not Federally enforceable.

Underground Injection Control Program

EPA authority for proposing regulations for state underground injection control programs is contained in Part C of the Safe Drinking Water Act. As envisioned by the latest draft regulations, the Underground Injection Control (UIC) program will encompass in situ mining of uranium under its Category III class of injection wells. Class III also includes Frasch process (sulfur) wells, in situ gasification, other solution mining processes, geothermal, and certain other wells.

Section 1422(a) of the Act requires EPA to list each State for which a UIC program may be necessary to ensure such activities will not endanger drinking water sources. EPA recently published its initial list of States on September 25, 1978, with Texas at the head of the list as determined by a "rating formula". The formula includes such factors as underground water uses, numbers of different kinds of wells, numbers of sites, volumetric rates, etc., but does not include a factor to account for adequacy of existing or projected State programs.

The UIC regulations define certain required elements of approvable State programs and designate procedures and requirements which must be met before States can be approved for primacy. The designated States will be required to establish UIC programs in accordance with the timetable of Section 1422(b) of the Act, which is triggered by publication of the Part 146 regulations just discussed.

As presently drafted, the UIC regulations reflect the clear Congressional intent that the States shall exercise the primary responsibility for enforcement to protect underground sources of drinking water. Should a listed State choose not to seek primacy, or if its program does not satisfy the requirements of the Act and applicable regulations, EPA will prescribe a program for the State and administer the program. The State program must meet a number of minimum conditions, such as prohibition of non-permitted injection activities, protection of underground sources of drinking water, inspection, monitoring, record-keeping, and reporting requirements, and coverage of Federal injection activities. Financial responsibility for proper well abandonment must be placed on the permittee, in the form of a performance bond.

EPA will exercise oversight, including access to documents, and reviews of annual reports and compliance reports required of primacy States. EPA also will retain authority for Federal enforcement against permittees in event a State fails to act, the

authority to propose revisions to State programs, and authority to withdraw primacy.

Section 1443 of the Safe Drinking Water Act provides for grants to States with approved programs, to carry out the UIC program.

5.3 Decommissioning and Surface Reclamation

Decommissioning should begin after completion of mining and groundwater restoration. Usually all surface buildings and equipment are disassembled and removed. The plant building may be left for the landowner subject to approval by the regulatory agency that the building is decontaminated. Tanks and foundations are removed from the mine site and all wells are plugged and sealed. Waste and evaporation ponds are emptied and tested for presence of radioactivity. Any radioactive solids present must be removed and disposed of at a licensed disposal site, such as an active uranium mill tailings pond. After the solids are removed, the pit should be filled and ready for surface reclamation.

Surface reclamation will be required for all disturbed areas: access and service roads, plant building area and evaporation pits and waste pond areas. In Wyoming, the Department of Land Quality, Land Quality Division requires a detailed reclamation plan and has authority to approve reclamation methods, seed mixtures, and timing of activities.

References

Chamberlain, Peter G. Evaluating Ore Bodies for Leaching with Permeability Measurements. Paper presented at the AIME Annual Meeting New Orleans, Louisiana, February 18-22, 1979. AIME Preprint Number 79-27.

De Vries, Frederick W. Novel Techniques in Lixiviants and Site Restoration. In proceedings of South Texas Uranium Seminar, Corpus Christi, Texas, September 10-13, 1978. Society of Mining Engineers of American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1979.

Environmental Protection Agency. Uranium Mining and Milling, The Need, The Process, The Impacts, The Choices - Administrator's Guide. Environmental Protection Agency, EPA-908/1-78-004, Denver, Colorado, May 1978.

Hancock, Bill. Uranium In Situ Leaching: Its Advantages, Practice, Problems, and Computer Simulations. Paper presented at the 107th annual meeting, AIME, Atlanta, Georgia, March 1977. AIME Preprint 77-AS-68.

Kasper, Dennis R. and William H. Engelmann. Compliance with Environmental Regulations for In Situ Uranium Mining: From Discovery to Closure. Paper presented at U.S. Bureau of Mines Technology Transfer Seminar on In Situ Uranium Mining, Denver, Colorado, July 1978.

Nuclear Regulatory Commission. Final Environmental Statement Related to Operation of Irigaray Uranium Solution Mining Project, Wyoming Mineral Corporation. NUREG-0481, September 1978.

_____. Final Environmental Statement Related to Operation of Highland Uranium Solution Mining Project, Exxon Minerals Company, U.S.A. NUREG-0489, November 1978.

_____. Final Report Ground-Water Elements of In Situ Leach Mining of Uranium. NUREG/CR-0311, August 1978.

Taylor, William R. Ground Water Quality Protection In Situ Uranium Mines. Paper presented at the 1979 AIME Annual Meeting New Orleans, Louisiana, February 18-22, 1979. AIME Preprint number 79-10.

White, Lane. Wyoming Uranium Miners Set Sight On Higher Production. Engineering and Mining Journal, December 1975, pp. 61-71.

Wyoming Mineral Corporation. Uranium Solution Mining. Lakewood, Colorado: Wyoming Mineral Corporation, 1976.

_____. Environmental Report, Keota Project, Weld County, Colorado. Lakewood, Colorado: Wyoming Mineral Corporation, August 1978.

Glossary

Alluvium. Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparitively recent geologic time as sorted or semisorted sediments.

Aquifer. Porous water-bearing formation (bed or stratum) of permeable rock, sand, or gravel capable of yielding significant quantities of water.

Area of influence. Area around a pumping well in which the water table or the piezometric surface (in confined aquifers) is lowered by pumping.

Barrens. In solution mining of uranium, chemical solution from which valuable uranium has been removed by precipitation or ion exchange before reuse.

Baseline. The environmental condition that existed prior to mining as determined by physical and/or chemical parameters and their natural variability.

Bleed system. A production adjustment technique whereby more fluids are pumped from the production zone than are injected, creating an inflow of groundwater into the production area.

Brine. A highly mineralized solution (usually greater than 100,000 mg/liter), especially of chloride salts.

Casing. Steel or plastic pipe or tubing that is placed in a borehole to prevent entry of loose rock, gas, or liquid or to prevent loss of drilling fluid.

Chemical water quality. The nature of water as determined by the concentration of chemical and biological constituents.

Clogging. Deposition of fine particles such as clay or silt at the surface and in the pores of a permeable porous medium, e.g., soil, resulting in the reduction of permeability.

Concentration. The weight of solute dissolved in a unit volume of solution.

Conductivity, hydraulic. Combined property of a porous medium and the fluid moving through it in saturated flow, which

determines the relationship, called Darcy's law, between the specific discharge and the head gradient causing it.

Cone of depression. The depression, ideally conical in shape, that is formed in a water table or potentiometric surface when water is removed from a well.

Confining bed. Formation overlying or underlying a much more permeable aquifer.

Consumptive use. That part of the water withdrawn that is no longer available because it has been evaporated, transferred, incorporated into products or crops, or otherwise removed from the immediate water environment.

Contamination. The degradation of natural water quality as a result of man's activities to the extent that its usefulness is impaired. There is no implication of any specific limits, since the degree of permissible contamination depends upon the intended end use, or uses, of the water.

Corrective actions. Those measures taken to ameliorate or terminate a situation at or near the source of the problem in order to prevent an uncontrolled release of radioactive or toxic material or to reduce the magnitude of a release, e.g., shutting down equipment, repair and damage control, or reorganizing pumping arrangements.

Curie. The quantity of any radioactive material giving 3.7×10^{10} disintegrations per second. A picocurie is one trillionth (10^{-12}) of a Curie, or a quantity of radioactive material giving 2.22 disintegrations per minute.

Darcy. Unit of intrinsic permeability defined as the permeability of a medium in which a liquid of dynamic viscosity of 1 centipoise discharges 1 cm^3/sec through a cross section of 1 cm^2 under a gradient normal to the section of 1 atm/cm.

Darcy's law. Law expressing the proportionality of the specific discharge of a liquid flowing through a porous medium to a hydraulic gradient in laminar flow (low Reynolds numbers).

Degradable. Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original; also referred to as biodegradable when readily decomposed by organisms.

Degradation of water quality. The act or process of reducing the level of water quality so as to impair its original usefulness.

Desorption. The reverse process of adsorption whereby adsorbed matter is removed from the adsorbent.

Dissolved solids, total (TDS). Total weight of dissolved material constituents in water per unit volume or weight of water in the sample.

Drawdown. Lowering of the water table or piezometric surface caused by the extraction of groundwater by pumping, by artesian flow from a borehole, or by a spring emerging from an aquifer.

Effluent. A waste liquid, solid, or gas, in its natural state or partially or completely treated, that discharges into the environment.

Eluant. The solution that removes (elutes) a material (uranium) adsorbed on ion exchange resin.

Excursion. The movement of lixiviant (leachate solution) out of a mine zone as evidenced by measured movement past a trend or monitor well. Measurement is by an increase of selected parameter values above their established upper control limits.

Groundwater. Water beneath the land surface in the saturated zone that is under atmospheric or artesian pressure; the water that enters wells and issues from springs.

Groundwater management. The development and utilization of the underground resources (water, storage capacity, and transmission capacity), frequently in conjunction with surface resources, in a rational and optimal manner to achieve defined and accepted water resource development objectives. Quality as well as quantity must be considered. The surface water resources involved may include imported and reclaimed water as well as tributary streams.

Hardness, carbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium bicarbonates (temporary hardness).

Hardness, noncarbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium salts other than carbonates (permanent hardness).

Hardness of water. That property of water, due mainly to bicarbonates, chlorides, and sulfates of calcium and magnesium, which prevents the production of abundant lather with soap.

Hazardous waste. Any waste or combination of wastes (which pose a substantial present of potential hazard to human health or living organisms) whose properties include flammability, evolution of toxic or irritating vapors, contact irritation, or human or animal toxicity.

Heavy metals. Metallic elements, including the transition series, which include many elements required for plant and animal

nutrition in trace concentrations but which become toxic at higher concentrations. Examples are mercury, chromium, cadmium, and lead.

Hydraulic gradient. The change in static head per unit of distance along a flow path.

Impoundment. A body of water formed by collecting water, as by a dam.

Infiltration. The flow of a liquid into soil or rock through pores or small openings.

Injection well. A well used for injecting fluids into an underground stratum or ore body by gravity flow or under pressure.

Ion excnange. Reversible exchange of ions absorbed on a mineral or synthetic polymer surface with ions in solution in contact with the surface. In the case of clay minerals, polyvalent ions tend to exchange for monovalent ions.

In situ. In its original or natural position.

Leachate. The liquid that has percolated through solid ore, waste, or other man-emplaced medium and has extracted dissolved or suspended material from it.

Leakage. In groundwater, the flow of water from or into an aquifer through an underlying or overlying semipervious layer.

Lixiviant. Leachate solution pumped underground to a uranium ore body; it may be alkaline or acid in character.

Mine field. Refers to the well-field area(s) and affected surface associated with solution mining. The term is often used interchangeably with well field.

Mine zone. The area from which uranium is extracted, including related buildings and structures. In this instance, it would include the ore body, all associated surface areas, and related well fields, process equipment, and buildings.

Mining Unit (production unit). A segment or portion of an ore body capable of economically supporting mineral extraction; the minable limits of an ore body, which would normally include several production fields.

Monitor well. A surveillance (observation) well located usually along the periphery of a well field. It is used to indicate containment and/or lixiviant migration beyond the well field boundary. When the upper control limit of a monitor well is exceeded, corrective action is initiated.

Monitor well zone. The area of possible monitor well location. This zone is normally outside the limits of mineralization.

Nonpoint source. A source from which the contaminant enters the receiving water in an intermittent and/or diffuse manner.

Nonproduction zone(s). Those stratigraphic intervals underlying and overlying the production zone that are aquifers or that are relatively permeable.

Ore body. The mineralized portion of the sandstone formation where uranium is found in various grades and concentrations that can be extracted economically.

Osmosis. Passage of a solvent from a dilute solution to a more concentrated one through a semipermeable membrane (one that is permeable to the solvent only).

Oxidation. A chemical reaction in which there is an increase in positive valence of an element from a loss of electrons; in contrast to reduction.

Permeability. Property of a porous medium to allow for the movement of liquids and gases through it under the combined action of gravity and pressure.

Permeable rock. Rock having a texture that permits water to move through it perceptibly under a head gradient ordinarily found in subsurface water (pervious rock).

pH. Minus the logarithm of the hydrogen ion concentration (activity). It is used as an indicator of acidity (pH less than 7) or alkalinity (pH greater than 7).

Piezometric surface. The surface defined by the levels to which water under artesian conditions will rise in tightly cased wells; also called potentiometric surface.

Plume. A body of contaminated groundwater originating from a specific source and influenced by such factors as the local groundwater flow pattern, density of contaminant, and character of the aquifer.

Point source. Any discernible confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or concentrated animal feeding operation, from which contaminants are or may be discharged.

Pollutants (water). Substances that may become dissolved, suspended, absorbed, or otherwise contained in water and impair its usefulness.

Pollution (water). The degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired.

Ponds. Small storage reservoirs.

Population at risk. Those persons for whom protective actions are being or would be taken.

Pore. An open space in rock or soil.

Porosity. The relative volume of the pore spaces between mineral grains in a rock as compared with the total rock volume.

Porous medium. Solid body containing interconnected pores more or less evenly distributed.

Production cell. The grouping of injection wells about a production or recovery well arranged in various configurations and varying in number.

Production field (zone unit). Mine or well field(s) actively used for production. It could consist of two or more well fields.

Production well (recovery well). A well from which lixiviant is recovered for conveyance to a process plant.

Production zone. That stratigraphic interval into which leaching chemicals are introduced. This interval extends horizontally in all directions in and beyond the production area.

Pump test. Extraction of water from a well at one or more selected discharge rates, during which piezometric or phreatic levels are measured regularly at the pumped well and at nearby observation wells. The data are used for determining the aquifer parameters in the vicinity of the pumped well.

Purification. Treatment of water for the removal of harmful or undesirable physical properties, chemical substances, and living organisms.

Radius of influence. Distance from the axis of a pumped or recharged well at which the effect of the well on the piezometric or the phreatic surface is no longer perceptible.

Recharge. The addition of water to the groundwater system by natural or artificial processes.

Reclamation. The return of the surface environment to acceptable preexisting conditions. This normally includes equipment removal, well plugging, surface contouring, reseeding, etc.

Reduction. A chemical reaction in which there is a decrease in positive valence as a result of gaining of electrons.

Restoration. The returning of all affected groundwater to its premining quality for its premining use by employing the best practical technology.

Roll front. Uranium deposition localized as a roll or interface separating an oxidized interior from a reduced exterior. The reduced side of this interface is significantly enriched in uranium.

Runoff. Direct or overland runoff is that portion of rainfall which is not absorbed by soil, evaporated, or transpired by plants but finds its way into streams as surface flow.

Seepage. Slow movement of water in unsaturated rock material; loss of water by infiltration into the soil from a canal or other body of water.

Solution channels. Fractures, joints, bedding planes, or other openings in soluble rocks, through which flow can occur (especially in limestone).

Sorption. A general term used to encompass processes of adsorption, absorption, desorption, ion exchange, ion exclusion, ion retardation, chemisorption, and dialysis.

Specific conductance. The ability of a cubic centimeter of water to conduct electricity; varies directly with the amount of ionized minerals in the water.

Subsidence. Surface caving or distortion brought about by collapse of deep mine workings or cavernous carbonate formations, or from overpumping of certain types of aquifers.

Surface water. That portion of water that appears on the land surface (oceans, lakes, rivers).

Toxicity. The ability of a material to produce injury or disease upon exposure, ingestion, inhalation, or assimilation by a living organism.

Transmissivity. Rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is expressed as the product of the hydraulic conductivity and the thickness of the saturated portion of the aquifer.

Uranium solution extraction. A term used by the NRC to describe what the Guide calls solution mining or in situ leaching.

Waste. Solids or liquids from solution mining or associated processes of no further value and subject to no additional productive processing. These are normally stored for concentration and ultimate disposal. Some process streams may be waste streams.

Water, brackish. Water containing significantly less salt than sea-water. The concentration of total dissolved solids is usually in the range of 1,000-10,000 mg/liter.

Water quality. Pertaining to the chemical, physical, and biological constituents found in water and its suitability for a particular purpose.

Water resources. Supply of water in a given area or basin interpreted in terms of availability of surface and underground water.

Water table. That surface in an unconfined groundwater body at which the pressure is atmospheric. It defines the top of the saturated zone.

Well, disposal. Well used for the disposal of polluted or drainage water brines, etc.

Well field. Several production cells capable of supplying a given feed to a process plant.

Source: Adapted from NRC, NUREG-0481, 1978 and Bureau of Mines dictionary of mining, mineral, and related terms, 1968.